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RESEARCH AND TECHNOLOGIC WORK ON EXPLOSIVES, EXPLOSIONS, AND FLAMES: FISCAL YEAR 1967

UNITED STATES DEPARTMENT OF THE INTERIOR

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by

Staff, Explosives Research Center

ERRATA

On page 12, in the paragraph headed "Evaluation of Electric Blasting Caps," the last sentence should read as follows:

> On the basis of these results, steel can be considered an acceptable substitute for copper in electric blasting caps for use in underground coal mines.

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RESEARCH AND TECHNOLOGIC WORK ON EXPLOSIVES, EXPLOSIONS, AND FLAMES: FISCAL YEAR 1967

by

Staff, Explosives Research Center[1]

INTRODUCTION

The principal activities of the Bureau of Mines Explosives Research Center during fiscal year 1967 (July 1, 1966, to June 30, 1967) are reviewed in part 1. Part 2 presents short abstracts of the publications issued during this period in the Bureau series and in other media. Part 3 describes a short study on the shock initiation of hydrogen peroxide not destined for publication elsewhere.

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Department of the Army
Department of Health, Education, and Welfare
Department of the Navy
National Aeronautics and Space Administration
Space Nuclear Propulsion Office

PART 1.--SUMMARY OF EXPLOSIVES RESEARCH CENTER ACTIVITIES IN FISCAL YEAR 1967

As in previous years the activities of the Center were grouped under two major programs--Explosion, Flames and Combustion Research; and Explosives Research and Evaluation. The essential objectives remained the same: to generate fundamental and practical information on explosion and combustion processes leading to greater safety in coal mining and other operations involving

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[1]Explosives Research Center, Bureau of Mines, Pittsburgh, Pa.

explosives and hazardous chemicals and to more efficient utilization of the national fuel resources. In some areas changes in program orientation reflected changes in the immediate demands made by sponsoring Government agencies and industry.

In support of the national space flight effort, a 3-year program on hard starts in Apollo-type rocket engines was completed. Hydrogen, widely used in space-flight facilities, was again the subject of two studies--one on disposal of waste hydrogen by flaring, the other on possible leakage of hydrogen into electrical equipment with resulting spark ignition hazard. The Bureau took a very active part in the investigation of the Apollo 204 accident, with the Research Director of the Explosives Research Center serving as a member of the Review Board. A fire in a chamber used for medical research under high-altitude conditions was also investigated. Utilization of conventional explosives to exploit mineral resources on the moon was the subject of continuing experimentation. The long-term investigation of the flammability and explosibility of conventional aircraft fluids was extended to pressures up to 15,000 psig.

Liquid explosives of the type used in propellants were the subject of several related studies designed to establish safety and performance criteria in terms of measurable chemical and physical properties. Two new experimental procedures for measuring explosive energy were developed and progress was made toward establishing mathematical models of reacting explosive systems suitable for high-speed computations. A patent was issued for an expendable pressure gage developed at the Bureau in connection with earlier detonation research. A review of the literature on airborne shocks from explosives was made.

In research to promote safety in industrial applications of explosives and hazardous chemicals, attention was again given to the special hazards created in underground coal mines by the simultaneous presence of methane and coal dust, by the sudden dispersion of coal dust by a gas explosion, and by the accumulation of methane in layers near the mine roof. An investigation was completed on the relative ignition hazard of various detonating cords that might be used in underground mines and a similar study was started on electric blasting caps.

The growing national concern with air pollution was reflected in the continuing study of factors controlling the emission of carbon monoxide, nitrogen dioxide, and light hydrocarbons by gas burner flames. The Bureau's well-known efforts to eliminate explosions in hospitals was extended to include fire hazards in hyperbaric chambers. The ubiquitous problem of spark-ignited gas explosions again received attention, as did the initiation of solid explosives by detonating gas mixtures. A number of potentially explosive chemicals were examined for sensitivity to various types of initiation. Substantial progress was made toward completing two new apparatus for measuring limits of flammability.

Ammonium nitrate explosive systems and especially slurries or water gels continued to be of much interest. One slurry and several high explosives were considered as candidates for explosive fracturing to stimulate the flow of gas and oil wells.

A third course on explosion problems in the chemical industry was presented in collaboration with personnel of the Health and Safety Research and Testing Center.

Fourteen papers were published in the Bureau series and other scientific publications during fiscal year 1967 (see part 2, pp. 28-38).[2] Ten papers were presented at meetings and conferences (see "Meetings and Conferences," pp. 25-28).[3]

Explosion, Flame, and Combustion Research

Hybrid Flames

Experiments with laboratory models simulating coal mine situations continued to provide information on the relationships between methane and coal dust concentrations required for lower limit flame propagation and the flame speeds of these mixtures (9).[4] Equivalences of coal dust to methane for lower limit horizontal and downward flame propagation in a duct, 1.8 m long with a 15.2-cm inside diameter, were obtained from these data. Fuel concentrations and equivalences are higher for steady flame propagation than for short-lived flame propagation in the immediate vicinity of an "overdriven" ignition. Equivalences were constant for horizontal propagation and varied inversely with the coal dust concentration for downward propagation. Stronger ignition sources tend to decrease required fuel concentrations at the lower limit and to increase the corresponding flame speeds.

Aerodynamics of Formation of Clouds of Float Coal Dust

Critical aerodynamic factors for entrainment of dust by weak gas explosions are being studied in an effort to develop means of preventing, or limiting, the formation of explosive dust clouds in a coal mine passageway. High-speed movies of air streams lifting dust ridges, designed to simulate deposits in a mine, showed the importance of intense reverse flow vortices in the wake region immediately behind a ridge. Initially erosion occurs at the ridge ends, edges, and crest. At minimal air velocities, erosion generally starts by detaching large clumps and lifting them vertically into the turbulent air stream where they are dispersed. The size and frequency of these detached clumps are increased by imposing large amplitude velocity pulsations on the air stream.[5]

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[2]Publications issued after June 30, 1967 are footnoted where pertinent but not abstracted.

[3]Papers presented after June 30, 1967, footnoted where pertinent.

[4]Underlined numbers in parentheses refer to publications in part 2.

[5]Singer, J. M., N. B. Greninger, Jr., and J. Grumer. Some Aspects of the Aerodynamics of the Formation of Float Coal Dust Clouds. Presented at 12th International Conference of Mine Safety Research Establishments, September 1967, Dortmund, Germany, 38 pp.

Flame Propagation in Layered Gas Systems

In the investigation of explosion hazards associated with methane accumulations near the mine roof, an experimental study was completed of slow flames propagating along the interface of gaseous fuel and air layers. The thickness of the flammable zone and the burning velocity of the stoichiometric mixture are the most significant factors controlling the flame speed. The former is influenced by the mixing time prior to the arrival of the flame. Mixing time also influences concentration gradients normal to the flame path which have a minor effect on flame speed, as does the position of the flame relative to the lower surface of the flame gallery. A study was made of the rupture of free detergent films of the type used to separate the fuel layer from the oxidant layer in these experiments.

The movement and distribution of gases near the interfacial flame was observed by particle track and interferometer methods. The relative velocity of the interfacial flame with respect to the unburned gas on the central streamline equaled the burning velocity of a homogeneous stoichiometric fuel-air mixture. The volume of fuel-air mixture observed in the combustion region was larger than was to be expected from the limits of flammability of the fuel.[6]

Hydrogen Safety

Studies on safety involving hydrogen[7] were extended to the determination of low flow stability limits of hydrogen diffusion flames on large diameter flare stacks (fig. 1). The objective is to promote safe operation in the development of nuclear propelled space vehicles and the fueling of liquid hydrogen-liquid oxygen propelled rockets. Two kinds of hazard limits have been identified; one occurs when a hydrogen diffusion flame dips into the mouth of a stack and the other when flame burns totally within the stack. Air for combustion within the stack is provided by downflow of air along the walls, counterbalanced by the buoyancy of the upflow of hydrogen through the central region of the stack.

Penetration of Hydrogen Into Electrical Equipment

This 2-year program was essentially completed in fiscal year 1967. According to extensive computations, supported by some experiments, thermal cycles, cross winds, and gaseous diffusion may have comparable effects in producing flammable hydrogen atmospheres in an electrical housing temporarily surrounded by a hydrogen-air mixture. The time required for the external mixture to penetrate the equipment in sufficient quantity to become a fire hazard

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[6]Liebman, I., H. E. Perlee, and J. Corry. Investigation of Flame Propagation Characteristics in Layered Gas Mixtures. BuMines Rept. of Inv. 7078, February 1968, 35 pp.

[7]Grumer, J., A. Strasser, and R. A. Van Meter. Safe Handling of Liquid Hydrogen. Cryogenic Eng. News, v. 2, No. 8, August 1967, pp. 60-63.

Strasser, A., I. Liebman, and S. R. Harris. Hydrogen Detectors. Cryogenic Eng. News, v. 2, No. 12, December 1967, pp. 16-20.

FIGURE 1. - Measuring the Effect of the Rate of Hydrogen Flow on the Stability of the Diffusion Flame.

could range from 1 minute to several hours. Theoretical consideration indicates that the flammable portion of the plume from a hydrogen leak will lie within an angle of ±5.5° from the plume center line within a distance of about 440 orifice diameters from the orifice.

Electrical Initiation of Gas Detonations

Single-frame photographs were obtained of detonation waves initiated directly by electric discharge in 60-40 percent hydrogen-oxygen mixtures at 1 atmosphere initial pressure. Analysis of these photographs indicates that a second shock occurs within the detonation before the detonation wave strikes the container wall and at a time when it can still be considered a freely expanding detonation. Such secondary shocks are well known in the case of exploding wire discharges which involve much higher energy and where, in the absence of combustible gas mixtures, they are attributed to interruptions in the current.

In the case of the spherical hydrogen-oxygen detonations, secondary shocks must be attributed to some other cause as space-time trajectories and the observed discharge current-time characteristics do not permit simple correlation with current interruptions. Investigations are continuing to determine the source of these secondary shocks.

Chronology and Topology of Sparks at Minimum Energy

Schlieren photographs (maximum framing rate, 25,000/sec) of expanding spark-ignited flame kernels of propane-air mixtures showed that they behave in the same way as the methane-air kernels studied earlier. At 0.1-atmosphere initial pressure, the kernel exhibits the characteristics of a self-propagating flame, 0.7 to 1 millisecond after passage of the ignition spark. Studies of hydrogen-air ignition kernels failed to establish comparable ignition time criteria.

Spark Ignition

Spark ignition experiments with pulse transformers showed that as much as 75 percent coupling efficiency can be obtained at energy levels of 1 millijoule or more. Although a combination of techniques may be needed for minimum energy determinations, the use of transformer coupling should simplify both equipment and procedure design.

Hypergolic Ignition and Combustion

This 3-year program was essentially completed in fiscal year 1967. The investigation was aimed at understanding and preventing the pressure spikes sometimes observed under simulated space-flight conditions during starts of attitude-control rocket engines of the type used in the Apollo program. Experimental firings in a simulated rocket engine with plastic sides established that the engine residue after firing consists largely of the explosive compound, hydrazine nitrate (HN).[8] To assess the effect of such accumulations, a systematic study was made of HN in water and in hydrazine solutions, emphasizing especially factors affecting combustion and detonation.[9] An intensive survey of the literature on HN was followed by experimental studies on the phase relations, density, viscosity, and surface tension of the HN-hydrazine and HN-water systems; infrared spectra of HN were determined. In the area of most immediate interest, the impact sensitivity of neat HN was evaluated and the critical film thickness for detonation of the HN solutions was determined in function of the HN concentration.

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[8] Christos, T., Y. Miron, H. K. James, and H. E. Perlee. Ignition Characteristics of Condensed-Phase Aerozine 50/Nitrogen Tetroxide Systems. J. Spacecraft and Rockets, v. 4, No. 9, September 1967, pp. 1224-1229.

Perlee, H. E., Y. Miron, and H. K. James. Preignition Phenomena in Small A-50/NTO Pulsed Rocket Engines. J. Spacecraft and Rockets, February 1968, pp. 233-235.

[9] Perlee, H. E., H. K. James, and Y. Miron. Preignition Mechanism of the Hydrazine-Nitrogen Tetroxide System. Presented at meeting of The Combustion Institute, Eastern Section, November 1967, Pittsburgh, Pa.

Fire and Explosion Hazards Assessment and Prevention Techniques for Aircraft

Ignition and flammability measurements of various combustible aircraft fluids made in earlier related work were extended to pressures up to 15,000 psig, for which no such data were known. The autoignition temperatures of several classes of lubricants in air did not vary much above about 4,000 psig.[10] In connection with this work, an apparatus for determining autoignition temperatures at extremely high pressures was developed and equipped with a 60,000-psig explosion chamber and a 30,000-psig air compressor.

Flame Characteristics Causing Air Pollution

In studies of factors that govern the emission of oxides of nitrogen, carbon monoxide, and light hydrocarbons by gas appliances such as space and water heaters, flame temperatures and concentration of air pollutants were measured for flames on enclosed burners designed to simulate these appliances. Pollutant concentrations determined in this way were compared with theoretical values (10).

Lean, stoichiometric, and rich propane-air flames were investigated both with and without simulated recycling of combustion gases.[11] Recycling reduced the concentrations of oxides of nitrogen by reducing the temperature in the primary combustion zone; certain maleffects were noted, particularly with respect to the escape of hydrocarbons. The temperature of the primary combustion zone can also be reduced by burner designs which promote heat transfer from the primary combustion zone to the burner port walls. At temperatures above about 2,500° F, the oxidation of carbon monoxide was strongly favored by increasing the oxygen concentration.

Flammability of Materials in Hyperbaric Atmospheres

The program was essentially completed in fiscal year 1967. To evaluate the fire hazards of combustible solids in hyperbaric atmospheres, hot-plate ignition temperatures, rates of flame spread, and minimum ignition energies were determined for a number of materials ordinarily present in hyperbaric hospital facilities. Measurements were made in air, in oxygen, and in various oxygen-nitrogen atmospheres at pressures from 1 to 6 atmospheres; some measurements were made in oxygen below 1 atmosphere.

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[10] This work, together with the results of earlier related programs sponsored by the Air Force is summarized in "Review of Ignition and Flammability Properties of Lubricants," by J. M. Kuchta and R. J. Kato. Tech. Rept. AFAPL-TR67-126, January 1968, 71 pp.

[11] Grumer, J., M. E. Harris, V. R. Rowe, and E. B. Cook. Effect of Recycling Combustion Products on Production of Oxides of Nitrogen, Carbon Monoxide, and Hydrocarbons by Gas Burner Flames. Presented at 60th Annual AIChE Meeting, New York, November 1967, 34 pp.

Minimum electrical ignition energies of the following anesthetics were also determined: cyclopropane, diethyl ether, divinyl ether, trichloroethylene, Fluoromar,[12] Fluothane, and chloroform.

There was a fairly good correlation between the oxygen partial pressure and the measured ignition temperatures and flame spread rates, although the latter appear to depend upon the oxygen concentration rather than on the total pressure. In several experiments, solid materials were ignited by electric sparks with energies of the same order (10 to 20 mj) as those which a human can discharge in low-humidity atmospheres.[13] Special importance must be attached to the observation that materials treated with certain fire retardants ignited in oxygen-rich atmospheres at lower temperatures than the untreated materials did.

Flammability Limits and Autoignition Temperatures: New Concepts and Experimental Methods

A semiautomated apparatus for determining limits of flammability of combustible gases and vapors was designed and partially constructed. Essentially it consists of a flammability tube with a traveling spark ignition source. The fuel and oxidant in predetermined concentrations are added in the tube by the movement of a mechanically operated porous steel piston.

A new apparatus was developed for measuring limits of flammability of sprays and fogs under flow conditions. It has the advantage of requiring relatively small samples even of liquids with high boiling points.

Explosives Research and Evaluation

Evaluation of Permissible Explosives in Predispersed Coal Dust

In the continuing study of the incendivity of permissible explosives in atmospheres containing both methane and coal dust, 34 permissible explosives (29 granular and 5 gelatinous) were examined.[14] The shots were fired unstemmed from a cannon into an atmosphere of 4 percent natural gas and 0.2 ounce per cubic foot of coal dust dispersed in air. The charge weight for 50 percent probability of ignition (W_{CDG}) for the granular explosives varied from

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[12]Reference to trade names is for information only and does not imply endorsement by the Bureau of Mines.

[13]Kuchta, J. M., A. L. Furno, G. H. Martindill, and A. C. Imhof. Ignition Temperatures and Flame Spread Rates of Materials in Oxygen-Enriched Atmospheres. Presented at meeting of The Combustion Institute, Eastern Section, Pittsburgh, Pa., November 1967.

Litchfield, E. L., and T. A. Kubala. Ignition Energy for Condensed Materials. Presented at meeting of The Combustion Institute, Eastern Section, Pittsburgh, Pa., November 1967.

[14]Mason, C. M., P. A. Richardson, and R. W. Van Dolah. The Incendivity of Permissible Explosives in Coal Dust-Gas Air Mixtures. BuMines Rept. of Inv. 2127, May 1968, 12 pp.

300 to 500 grams for five explosives containing up to 3 percent sodium chloride and from 390 to more than 906 grams for 24 explosives with 10 percent sodium chloride. The W_{CDG} values for the gelatinous explosives ranged from 134 to 650 grams. The spread of the W_{CDG} values suggests that this procedure could develop into a useful test method.

Explosive Characteristics of Ammonum Nitrate Slurries

Ammonium nitrate-water slurries sensitized with aluminum were evaluated under the conditions of gallery test 4, modified by predispersion of coal dust; the weight of explosive for 50 percent probability of ignition (W_{50}) ranged from 93 to 359 grams. In gallery test 7, the same compositions had W_{50} values from 415 to 700 grams.[15]

The possibility of a channel effect was investigated by firing a slurry contained in 1-inch polyethylene tubing from a conventional cannon. The detonation velocity and extent of propagation were determined with a resistance wire probe. Oscilloscope records showed no detectable channel effect. The sensitivity to initiation by a No. 6 electric blasting cap varied with the amount of air in the slurry, disappearing in some cases as the amount of entrained air was decreased. The temperature history of the slurries did not appear to affect their cap sensitivity, which remained unchanged when samples were heated to 95° C and then cooled to 25° C. Concentrations of carbon monoxide and oxides of nitrogen (Crawshaw-Jones method) in the detonation products were very low.

Initiation of Detonation in Solid Explosives by Gas-Phase Detonations

Fundamental studies on initiation of secondary explosives by gas detonations were continued. Results demonstrated that stores of these explosives would not be initiated to detonation by gas-phase detonations with an initial pressure of 1 atmosphere. Critical initial pressures were defined for a number of explosives.[16]

Incendivity of Detonating Cord

This investigation was completed during fiscal year 1967.[17] It resulted in a method suitable for evaluating the relative incendivity of detonating

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[15] Van Dolah, R. W., C. M. Mason, and D. R. Forshey. Development of Slurry Explosives for Use in Flammable Gas Atmospheres. Presented at 12th International Conference of Mine Safety Research Establishments, Dortmund, Germany, September 1967, 12 pp.

[16] Weiss, M. L., T. J. Schellinger, and E. L. Litchfield. Initiation of Condensed Explosives by Gas Detonations. Presented at 154th National Meeting of American Chemical Society, Chicago, Ill., September 1967. Preprinted by ACS Div. of Fuel Chem., v. 11, No. 4, pp. 142-151.

[17] Mason, C. M., J. L. Uraco, and J. C. Cooper. Development of a Method for Measuring Relative Incendivity of Detonating Cord. Presented at 12th International Conference of Mine Safety Research Establishments, Dortmund, Germany, September 1967, 10 pp.

cord in natural gas-air mixtures. The criterion is the number of strands of cord required to ignite the gas-air mixture in 50 percent of the shots, when short lengths of cord are fired as bundles suspended in the flammable gallery atmosphere. Factors investigated included the weight and composition of the core and the sheath and the most effective use of the flame quenching agent, potassium acid tartrate.

Computer Studies of Explosive Reactions

The goal of this new project is to predict the hazard potential of condensed-phase explosive systems using mathematical models of the physical and chemical processes which the systems undergo. The resulting mathematical equations are to be solved by high-speed digital computer. Special problems being considered include acceleration of deflagration in a granular material through forced convection and inertial confinement of the hot products, the ignition of a bubble in a reactive liquid by compression and expansion, and instabilities in the growth of a gasifying surface in a reactive liquid.

Airborne Shocks From Explosive Blasting

A literature search is being made in preparation of a publication on the subject. This will be followed by a field investigation to obtain additional information to relate blasting results with sound and shock propagation information developed by other programs, including sonic boom research.

Improvements in Energy Coupling of Commercial Explosives and Blasting Agents

Relative energy yields of 29 commercial explosives were assessed by two methods new to this field. The results were correlated with the strength of the explosive, its incendivity to methane and coal dust, and other characteristics. The new techniques measure, respectively, (1) the kinetic energy imparted by the detonating charge to a metallic casing which surrounds it and (2) the off-end pressure as recorded by an expendable pressure transducer system. For the explosives investigated, the energy transfer values typically ranged from about 600 to 1,300 joules per gram; these values may be compared with 1,420 joules per gram for ANFO and about 3,000 joules per gram for typical military high explosives. Delivered gage pressures ranged from approximately 10 to 50 kilobars with the majority of the explosives delivering 20 kilobars or less, as compared with pressures above 200 kilobars developed by military high explosives.

Multidisciplinary Research Leading to Utilization of Extraterrestrial Resources

The effect of exposure to moderate vacuum was studied for two conventional high explosives, RDX (cyclotrimethylene trinitramine) and tetryl, each evaluated at two densities to allow for permeability effects. Evaluation by a modified card-gap technique showed no significant change in explosive sensitivity at pressures down to 3×10^{-4} mm Hg. Since hexanitrostilbene, developed by the Naval Ordnance Laboratory and the prime explosive proposed for lunar

use, has an even lower vapor pressure than RDX or tetryl, its detonation should not be affected by leaks in encapsulation during long periods at the extremely low lunar pressures.

Oil and Gas Well Stimulation by Liquid Explosives

Several systems that are being considered by the Bartlesville Petroleum Research Center for use underground as fracturing agents were evaluated for detonability. Conventional blasting oil (nitroglycerin with additives) is a prime candidate; tetranitromethane (TNM)-benzene and TNM-octane are being considered for thermal fracture. As these systems have gap values in excess of 10 inches, extreme care is mandatory in handling them, especially the TNM mixtures which appear to develop high-velocity detonation quickly at these gaps.

An alternate system based on an ammonium nitrate-water slurry appears promising as regards ease of manufacture, cost, and safety. Its use in a field trial at an oil shale site in Wyoming is anticipated early in fiscal year 1968.

Propellant Ingredient Safety

Detonation reactions were studied in a number of liquid explosive systems that tend to undergo low-velocity detonation. In general, experimental results were in accord with the theoretical model describing low-velocity detonation in nitroglycerin-based explosives.

A study was initiated on the shock sensitivity of several rocket fuels using the instrumented card gap and the precavitated shock and wedge techniques to compare them with substances of well-known detonability.

In collaboration with the Stanford Research Institute, a memorandum on the handling of hazardous liquids was prepared for distribution to the propellant industry by the Office of Naval Research.[18]

Stress Waves in Bounded Media

An extensive program, employing flash radiography, was conducted to determine the energy transfer from a variety of high explosives to metal components in geometries that differ from previous studies using slab symmetry. A number of new explosive compositions were developed and studied in this connection.

Detonation Zone Structure and Reaction Kinetics

Time-resolved measurements of the electrical conductivity of the products generated by shocking a sample of explosive at pressures ranging from the threshold pressure for detectable reaction to the pressure of a fully

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[18]"The Safe Handling of High-Energy Liquids." Memorandum (Mar. 20, 1967) from Chief of Naval Research, U.S. Department of the Navy, Washington, D.C., to Chemical Propulsion Information Agency mailing list and chemistry departments of selected universities, 2 pp.

developed detonation were used to study reaction rates in the detonation zone of condensed-phase secondary explosives. It is hoped to establish a relationship between electrical conductivity and the physical and chemical properties of the detonation products.

Evaluation of Electric Blasting Caps

Instantaneous electric blasting caps with steel, copper, and aluminum shells were evaluated in an 8 percent natural gas-air mixture in the 45-cubic-foot gallery. The number of caps required for 50 percent probability of ignition of the gallery atmosphere (N_{50}) was determined for each type of shell. The N_{50} values were about 3.6 for copper shells and 3.3 for steel shells, whereas the aluminum caps gave 10/10 ignitions with single caps. On the basis of these results, steel can be considered an acceptable substitute for aluminum in electric blasting caps for use in underground coal mines.

New Methods of Hazards Evaluation

Shock sensitivity and the tendency to transit from deflagration to detonation were evaluated for several ammonium nitrate (AN) systems under the confinement provided by 2-inch-diameter steel containers, using the shock from 160 grams of tetryl to initiate the sample charge. Prilled AN mixed with 2 to 7 percent amorphous graphite detonated at 25° C. Prilled AN mixed with 2 percent organic surfactant detonated only above 120° C. None of these mixtures underwent transition from deflagration to detonation. Liquid ammonia saturated with AN (Diver's solution) did not propagate detonation when evaluated at -6° C in the same type of 2-inch steel containers.

The addition of potassium chloride to AN-sulfur mixtures did not increase their tendency to transit from deflagration to detonation; this is in contrast to the marked effect on thermal stability of such mixtures seen in earlier studies.

The ternary system nitromethane-anhydrous hydrazine-methanol was examined for shock sensitivity and detonation velocity at 25° and 50° C. At 25° C, the detonable range in 1-inch charges covered about one-half of the ternary composition diagram.

Potential Hazards of Propargyl Halides and Allene

Propargyl bromide, propargyl chloride, and allene (propadiene) were examined for ignitibility, monopropellant combustion, and detonability. The bromide is easily ignited by impact. Addition of toluene reduces the liquid-phase burning rate of both halides significantly. At ambient temperature, the materials cannot be initiated to stable detonation in diameters up to 2 inches. All three compounds are capable of monopropellant combustion in the liquid and vapor phases. Propargyl bromide burns at very low initial pressures--a fact that is significant in evaluating the hazard associated with its use.

Tunnel Destruction

Increased military demands with respect to the length and overburden of Earthen tunnels to be destroyed in Vietnam made it necessary to substitute condensed-phase explosives for the gaseous systems initially considered. The safety and performance of several candidate explosives were evaluated (card-gap, air-gap, and projectile-impact tests) and sensitized nitromethane was selected as the most promising. In a demonstration shot, sensitized nitromethane successfully destroyed a tunnel with a 31-foot silty clay overburden.[19]

Testing of Explosives and Hazardous Materials

A number of potentially explosive compounds and mixtures were examined for their reaction to impact, friction, static sparks, and heat (table 1).

TABLE 1. - Compounds examined during fiscal year 1967

Sample	Impact test, height, cm[1]		Static spark test energy, joules[4]	Ballistic mortar, percent of TNT
	Method 1[2]	Method 2[3]		
Hydrazine nitrate................	25	10	12.5	142
3,5-Dinitrosalicylic acid, 5-nitrofurfurylidene hydrazide..	106	-	-	67
Monomethyl hydrazine.............	>330	17	-	136
Unsymmetrical dimethyl hydrazine nitrate.........................	>330	34	-	106
Green dye smoke[5].................	106	-	0.013	-
Red dye smoke....................	70	-	0.013	-
Yellow dye smoke.................	111	-	0.0069	-
Violet dye smoke.................	96	-	0.013	-
Nitromethane.....................	-	-	-	119

[1]Height of drop of a 5-kg weight for 50 percent probability of ignition.
[2]One-half-inch-diameter cup with a closely fitting striker pin.
[3]Type No. 12 tool.
[4]Maximum energy for zero probability of ignitions using a potential of 5,000 volts.
[5]Pyrotechnic flare mixture.

No new or modified permissibles were submitted for testing in fiscal year 1967; one new certificate was issued for a permissible explosive. Eighteen field samples of permissible explosives satisfied all specifications of Schedule 1-H; two field samples failed gallery test 7.

Estimated consumption of permissible explosives in 1967 again showed a decrease as compared with the previous year (table 2).

[19]This and other field trials were carried out at a strip mine near Paris, Pa., made available by the Weirton Ice and Coal Supply Co.

TABLE 2. - Industrial consumption of explosives, in millions of pounds, January 1965 to December 1967[1]

	Coal mining			Total		
	1965	1966	1967	1965	1966	1967
Permissible explosives..........	73.6	71.1	[2]69	76.0	74.2	[2]72
Other high explosives, blasting agents, and unprocessed ammonium nitrate........................	515.7	534.1	([3])	1,868.3	1,911.3	([3])
Black powder......................	0.14	0.17	([3])	0.84	0.46	[2]0.50
Liquid oxygen.....................	5.6	13.1	([3])	5.6	13.1	([3])
Consumption ratio of permissible explosives to black powder......	526.0	419.0	-	-	-	-

[1]Based on Bureau of Mines Mineral Industry Survey, Explosives Annual.
[2]Estimated
[3]Not available.

Another major advance in safety in coal mining was made, thanks largely to the prolonged efforts of the Bureau, when the use of black powder in underground coal mines was finally outlawed by Public Law 89-376, passed on May 26, 1966, and effective October 1, 1966.

Investigation of Actual and Potential Disasters

The Bureau participated intensively in the 3-month investigation into the Apollo 204 disaster (Cape Kennedy, Fla., Jan. 27, 1967) involving a flash fire which caused the death of three astronauts. The Research Director, Explosives Research Center, served on the Apollo 204 Review Board and collaborated on the 2,500 page report of the Board. A concomitant investigation, conducted at the request of the National Aeronautics and Space Administration, showed that under the action of intense heat, mixtures of ethylene glycol and water which are ordinarily nonflammable can burn in oxygen.

The Bureau also took part in the investigation of a fire in a simulated altitude chamber which killed two men at the Brooks Air Force Base (San Antonio, Tex., Jan. 31, 1967). Ignition was attributed to sparking from a defective electric cord.

Patents: Pressure Gage

Notice of allowance for issuance of a patent (U.S. Pat. 3,341,797, granted Sept. 12, 1967) was received for an expendable pressure gage developed at the Explosives Research Center by Richard W. Watson. The gage provides a practical and economical means of determining pressures associated with blast, shock, and explosive waves.[20]

[20]Watson, R. W. Gauge for Determining Shock Pressures. Rev. Sci. Instr., v. 38, No. 7, July 1967, pp. 978-980.

Courses on Explosives

In December 1966 a third course on "Explosion Problems in the Chemical Industry" was presented by the Explosives Research Center, assisted by the Health and Safety Research and Testing Center. Twenty-six representatives from chemical and related industries attended the sessions.

At the request of the Pittsburgh (Pa.) Police Department, a 2-day explosive information course was held for the benefit of a new Special Services Squad.

Meetings and Conferences

Explosives Research Center personnel presented 10 papers at meetings and conferences as follows:

Explosion Hazards of Ammonium Nitrate Under Fire Conditions, by R. W. Van Dolah, at the National Meeting of the American Institute of Chemical Engineers, Atlantic City, N.J., September 1966.

Reduction of Incendivity of Hot Gases to Methane and Coal Dust by Sodium Chloride and Sodium Nitrate, by J. M. Singer, N. E. Hanna, R. W. Van Dolah, and J. Grumer,[21] at the 152d National Meeting of the American Chemical Society, New York, September 1966.

Flame Characteristics Causing Air Pollution. Production of Oxides of Nitrogen and Carbon Monoxide, by J. M. Singer, E. B. Cook, M. E. Harris, V. R. Rowe, and J. Grumer,[22] at the 152d National Meeting of the American Chemical Society, New York, September 1966. This paper was also presented at the American Gas Association Basic Research Symposium, Chicago, Ill., March 1966.

A Wedge Technique for Investigation of Detonation in Liquid Explosives, by J. Ribovich, at the New York Academy of Sciences Conference on Prevention of and Protection Against Accidental Explosions of Munitions, Fuels, and Other Hazardous Mixtures, New York, October 1966, 19 pp.

Large-Scale Sympathetic Detonation Investigations, by R. W. Van Dolah, at the New York Academy of Sciences Conference on Prevention of and Protection Against Accidental Explosions of Munitions, Fuels, and Other Hazardous Mixtures, New York, October 1966, 25 pp.

Mechanisms Relevant to Initiation of Low-Velocity Detonations, by J. E. Hay and R. W. Watson, at the New York Academy of Sciences Conference on

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[21]Singer, J. M., N. E. Hanna, R. W. Van Dolah, and J. Grumer. Reduction of Incendivity of Hot Gases to Methane and Coal Dust by Sodium Chloride and Sodium Nitrate. BuMines Rept. of Inv. 6954, 1967, 15 pp. (11).

[22]Singer, J. M., E. B. Cook, M. E. Harris, V. R. Rowe, and J. Grumer. Flame Characteristics Causing Air Pollution. Production of Oxides of Nitrogen and Carbon Monoxide. BuMines Rept. of Inv. 6958, 1967, 34 pp. (10).

Prevention of and Protection Against Accidental Explosions of Munitions, Fuels, and Other Hazardous Mixtures, New York, October 1966, 29 pp.

A New Look at Sympathetic Detonation of Explosives and Related Materials, by R. W. Van Dolah, at the National Safety Congress, Chicago, Ill., October 1966.

Evaluation of Substances for Fire and Explosion Hazards and Technical Basis for Tests, by R. W. Van Dolah, at the National Academy of Sciences Committee on Hazardous Materials, Houston, Tex., November 1966.

Ignition Characteristics of Condensed-Phase Aerozine 50/Nitrogen Tetroxide Systems, by T. Christos, Y. Miron, H. K. James, and H. E. Perlee,[23] at the Third Interagency Chemical Rocket Propulsion Conference, Cape Kennedy, Fla., November 1966.

Explosion Hazards of Ammonium Nitrate Under Fire Exposure, by R. W. Van Dolah, at the Society of Fire Protection Engineers, New York, January 1966.

Current Bureau of Mines research on ammonium nitrate was presented by the Explosives Research Center's Research Director at a symposium jointly sponsored by the Belgian Sections of the Société de Chimie Industrielle and The Combustion Institute, Brussels, Belgium, May 1967. Informal talks on Bureau detonation research were given at seminars of the Section of Detonics and Combustion, National Committee for Mechanics, Royal Institute of Technology, Stockholm, Sweden; the Nitro Nobel AG, Gyttorp, Sweden; and the Norse Sprengstoff industri, Oslo, Norway.

Other meetings attended by Explosives Research Center personnel included the 11th International Combustion Symposium, Berkeley, Calif., August 1966; the Fall Meeting of the National Fire Protection Association, Raleigh, N.C., November 1966; the 22nd Meeting of the Interagency Chemical Rocket Propulsion Group on Liquid Propellant Test Methods, Houston, Tex., March 1967; the Fire Hazard and Extinguishment Conference, San Antonio, Tex., May 1967; the Counterinsurgency Research and Development Conference, Houston, Tex., June 1967; and the Third Air Force Office of Scientific Research Contractors' Meeting on Combustion Dynamics Research, Cocoa Beach, Fla., June 1967.

The Research Director of the Explosives Research Center represented the United States on the international Group of Experts on Unstable Substances of the Organization for Economic Cooperation and Development. Members of the Center represented the Bureau on several committees of the National Fire Protection Association, the American Chemical Society, the American Gas Association, the American Society for Testing and Materials, and various working groups of military and civilian Government agencies.

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[23] Christos, T., Y. Miron, H. K. James, and H. E. Perlee, Ignition Characteristics of Condensed-Phase Aerozine 50/Nitrogen Tetroxide Systems. J. Spacecraft and Rockets, v. 4, No. 9, September 1967, pp. 1224-1229.

FIGURE 2. - Test Facility Showing 12-Foot Diameter Spherical Steel Vessel.

PART 2.--PUBLICATIONS DURING FISCAL YEAR 1967[24]

1. Bartkowiak, A., and J. M. Kuchta. A Large Spherical Vessel for Combustion Research. I&EC Process Design and Development, v. 5, October 1966, pp. 436-439.

Limits of flammability and detonability reported for many gases and vapors often differ, largely due to wall effects. However, it has been shown that if the vessel in which these limits are determined is sufficiently large, these effects tend to disappear. Accordingly the Bureau designed and installed at its Bruceton facility a 12-foot-diameter spherical steel vessel (fig. 2). Constructed of steel that has high tensile strength and resistance to brittle fractures (A-212 B firebox quality), the vessel has a maximum design of 300 psig. Inner and outer doors allow personnel to circulate and permit experiments over a wide range of pressures. It can be used for solid explosives as well as for vapors and gases.

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[24]Publications are listed alphabetically according to senior author.

2. Cato, R. J., W. H. Gilbert, and J. M. Kuchta. Effect of Temperature on Upper Flammability Limits of Hydrocarbon-Fuel Vapors in Air. Fire Technol., v. 3, No. 1, February 1967, pp. 14-19.

The effect of temperature on the upper limit of flammability of the fuel vapor-air mixtures was examined for several straight chain saturated hydrocarbons (propane, butane, pentane, hexane, heptane, octane, decane) and the hydrocarbon jet fuel JP-6. The effect of temperature was greater than predicted by a modified Burgess-Wheeler law for "hot" flame propagation. Where autoignition is a practical possibility, limits of flammability of a given system should be known for temperatures as high as those which are near critical for ignition.

3. Grant, R. L. A Combination Statistical Design for Sensitivity Testing. BuMines Inf. Circ. 8324, 1967, 25 pp.

Application of the Bruceton up-and-down method with factorial design to the testing of experimental designs has been hampered by the recommendation that at least 50 trials be made per sequence. To determine whether shorter sequences would be useful, frequencies of 20 trials were investigated at the test gallery of the Bureau of Mines, Bruceton, Pa. Permissible explosives were fired from the cannon into a flammable natural gas-air atmosphere. Results showed that the shorter sequence leads to useful conclusions and reduces the cost of the experimental program.

4. Grant, R. L., N. E. Hanna, and R. W. Van Dolah. New Gap Sensitivity Methods for Explosives. BuMines Rept. of Inv. 6947, May 1967, 17 pp.

Two new gap sensitivity methods were developed and applied experimentally. These methods use full cartridges confined in rigid cardboard tubes. One method uses an air gap, the other a coal dust gap to simulate conditions found in coal mine boreholes. Both are based on the statistical up-and-down method and give more useful values for the 50 percent gap than the schedule half-cartridge test. Sixty samples of permissible explosives were evaluated by the two new methods and by the schedule half-cartridge method. The schedule test has the disadvantage that a half-cartridge may not be long enough for the explosive to attain maximum detonation velocity; in addition the procedure tends to be statistically inefficient because most of the tests are conducted near the tail of the probability curve.

5. Grant, R. L., J. N. Murphy, and M. L. Bowser. The Effect of Weather on Sound Transmission From Explosive Shock. BuMines Rept. of Inv. 6921, 1967, 13 pp.

In connection with the severe noise problem created by explosive activities at the Bureau of Mines, Bruceton, Pa., facilities, a study was made of the effect of weather conditions on the propagation of sound in the near field (to within a radius of 2 miles from the noise source). The degree of correlation between sound transmission and atmospheric conditions was analyzed by automatic computational methods. Statistical analysis of data collected during 5 months indicates that the following weather variables affect transmission of sound through the atmosphere in order of decreasing importance: Wind

velocity and wind direction, with winds moving in the same direction as the sound wave increasing sound intensity and duration; barometric pressure, with high pressures decreasing sound intensity and duration; atmospheric temperature, with high temperatures again decreasing sound intensity and duration. Temperature inversions did not affect sound propagation under the conditions of the investigation.

6. Kuchta, J. M., and R. J. Cato. Hot Gas Ignition Temperatures of Hydrocarbon Fuel Vapor-Air Mixtures. BuMines Rept. of Inv. 6857, 1966, 14 pp.

Most of the ignition temperatures of combustible fluids reported in the literature were measured using hot vessels, wires, or tubes as ignition sources. However, jets of hot gas can also ignite combustible gases or vapors, as for instance, during rupture of an oil seal in a jet engine or following a borehole shot in a coal mine. Accordingly, jets of hot air (1/8- to 3/4-inch-diameter) were used to determine hot gas ignition temperatures of the following combustible vapors mixed with air: n-hexane, n-octane, n-decane, JP-6 jet fuel, and an adipate ester engine oil (MIL-L-7808). Minimum ignition temperatures were observed at a fuel-air weight ratio of about 0.5; within the experimental region they were virtually independent of fuel concentration and of moderate changes in jet velocity. The minimum ignition temperatures decreased as the jet diameter increased. For the same size heat source and the same ignition criterion, the hot gas ignition temperatures of the combustibles investigated were not necessarily much higher than the autoignition and hot wire ignition temperatures.

7. Kuchta, J. M., and G. H. Martindill. Thermal Oxidation of n-Octane Vapour-Oxygen-Nitrogen Mixtures at Reduced Pressures. Combustion and Flame, v. 11, No. 3, June 1967, pp. 212-216.

Many paraffin hydrocarbons can burn as "cool" or "hot" flames, depending on the temperature, pressure, and composition of the combustible mixture. In some cases temperature rises associated with "cool" flames may be greater than the system can tolerate safely (100° to 200° C). To obtain further information on this potential hazard, the slow oxidation of n-octane vapor-oxygen-nitrogen mixtures was investigated at reduced pressures ($P_t \geq 35$ mm Hg) and at temperatures up to where rapid reactions or "cool flames" occurred. At 250° C the rates of pressure rise depended more on total pressure than on the fuel and oxygen concentrations. The critical pressure for rapid reaction, characterized by an abrupt pressure rise, decreased with decreasing temperature, fuel concentration, and vessel radius. No abrupt pressure rises were observed above about 290° C, and the reaction became less temperature and pressure dependent. The rate data were reasonably consistent with those calculated from thermal ignition theory.

8. Litchfield, E. L., and M. H. Hay. Detonation Initiation in Alkane-Oxygen Mixtures. BuMines Rept. of Inv. 6840, 1966, 6 pp.

Methods developed by the Bureau of Mines for direct initiation of detonation by electric discharge were applied to the following straight chain hydrocarbon fuel gases mixed with oxygen: methane, ethane, propane, butane, and

hexane. The gas mixture was contained in a steel vessel; the initiation source was an exploding wire; the minimum electric energy stored on a capacitor required to initiate detonation of mixtures with one-half to twice the stoichiometric fuel ratios was determined at 1 and 0.5 atmospheres. No detonation could be initiated in methane at 1 atmosphere for energies up to 484 joules. With the other hydrocarbons the most easily initiated mixture detonated for energies between 24 and 33 joules (1 atm) and 28 and 43 joules (0.5 atm).

Methane was also investigated as a diluent to suppress detonation initiation of hydrogen-oxygen mixtures. Volume-for-volume methane was more effective as a detonation inhibitor than the fire-fighting additives methyl chloride, bromotrifluoromethane, and 1,2-dibromotetrafluoromethane.

9. Singer, J. M., E. B. Cook, and J. Grumer. Equivalences and Lower Ignition Limits of Coal Dust and Methane Mixtures. BuMines Rept. of Inv. 6931, 1967, 35 pp.

Fuel concentration limits for ignition of mixtures of coal dust-methane and air were determined using ignition of hot jets from the explosion of stoichiometric mixtures of methane, oxygen, and nitrogen. Four types of coal dust were examined (Pittsburgh seam, Sewell No. 2 seam, Pocahontas No. 3 seam, and anthracite). Coal dust concentrations were less than 80 milligrams per liter. The hybrid mixtures examined were ignitible when the concentration of each component was less than its lower limit of flammability. Higher ignition jet temperatures were required to ignite lower limit mixtures of hybrid fuels or coal dust than to ignite lower limit mixtures of methane. Lower concentrations (weight of fuel per unit volume of air) of coal dust than of methane could be ignited when the coal dust was finely powdered and from a relatively ignitible coal. Equivalence between coal dust and methane at the lower ignition limit could not be explained on the basis of substituting the thermal value of one fuel for the other. The equivalence varied inversely with the temperature of the ignition source and directly with the coal dust particle size and concentration. There was some evidence of synergism between coal dusts that ignite with relative ease and methane. Relatively large coal dust particles did not contribute their total weight to the effect of fuel concentration at the ignition limit because of insufficient time for the particle to heat up and burn completely. Neither the volatile percentage of coal dust, its specific area, nor the product of these factors was a sufficient measure of relative ignitibility. Regression of surface does not appear to be the only mechanism for particle burning; there may be some fragmentation of the particle for particles small enough to equilibrate thermally with an ignition jet of relatively high temperature and thermal energy. Fragmentation could be caused by internal pressures produced by pyrolysis.

10. Singer, J. M., E. B. Cook, M. E. Harris, V. R. Rowe, and J. Grumer. Flame Characteristics Causing Air Pollution: Production of Oxides of Nitrogen and Carbon Monoxide. BuMines Rept. of Inv. 6958, 1967, 34 pp.

Equations for computing concentrations of carbon monoxide and nitric oxide in burned gases of lean, rich, and stoichiometric propane-air flames

were derived from thermodynamic and kinetic flame data taken from the literature. Computed concentrations of carbon monoxide and nitric oxide usually agreed to within a factor of 2 to 7 percent of concentrations observed downstream of flat grid-type burner propane-air flames. Computed concentrations were also in fair agreement with experimental values reported by several other investigators. Cooling the burned gas at different rates and/or recycling cold fuel gases into the primary fuel-air mixture were examined as means of reducing the final concentration of air pollutants. Lowering the primary flame temperature of lean mixtures by recycling cold fuel gas (with and without excess air) reduced emission of nitric oxide and increased emission of carbon monoxide. Cooling rates of about 5,500° and 10,000° R per second, starting at about 3,500° R, generally prevented nitric oxides concentrations from increasing much above the initial value at the primary combustion zone and did not prevent oxidation of initial concentrations of carbon monoxide.

11. Singer, J. M., N. E. Hanna, R. W. Van Dolah, and J. Grumer. Reduction of Incendivity of Hot Gases to Methane and Coal Dust by Sodium Chloride and Sodium Nitrate. BuMines Rept. of Inv. 6954, 1967, 15 pp.

Earlier studies by the Bureau of Mines had established that sodium chloride reduces the incendivity of explosives. The present study was designed to evaluate the effect of sodium nitrate in reducing ignition hazards. In gallery experiments, sodium nitrate reduced the incendivity of certain explosives to 8 percent natural gas and air but increased their incendivity to coal dust predispersed in air. In laboratory experiments using hot jets from explosions of stoichiometric mixtures of methane-oxygen-nitrogen as ignition sources, both sodium chloride and sodium nitrate reduced the incendivity to methane, to mixtures of coal dust and methane, and to coal dust. The difference between the results obtained in the gallery and in the laboratory with respect to the ignition of coal dust is attributed to temperature-time effects.

12. Staff, Explosives Research Center. Research and Technologic Work on Explosives, Explosions, and Flames: Fiscal Year 1965. BuMines Inf. Circ. 8308, 1966, 19 pp.

Major activities of the Bureau of Mines Explosives Research Center during fiscal year 1965 (July 1, 1964-June 30, 1965) are reviewed briefly. Part 1 summarizes significant accomplishments of the projects that were active during that report period. Part 2 represents short abstracts of the publications that appeared in the Bureau series and in other media during fiscal year 1965.

13. Hanna, N. E., P. A. Richardson, and R. W. Van Dolah. An Improved Method for Evaluating the Incendivity of Explosives to Coal Dust. A Progress Report. BuMines Rept. of Inv. 6815, 1966, 13 pp.

As part of a program to improve techniques for testing permissible explosives, the Bureau undertook to develop a method for evaluating the incendivity of explosives in coal dust-air or coal dust-natural gas which would be more discriminating than test 4 of Schedule 1-H. The Bruceton up-and-down method of statistical design was applied to results of suspended shots in a predispersed gas-air mixture. A device was developed for measuring coal dust

concentrations in the air-gas mixtures and dispersing the dust in the gallery atmosphere. The new method discriminates between different explosives with respect to their relative incendivity. Maximum ignition probability of the coal dust cloud by permissible explosives was observed for 0.3 ounce per cubic foot of dispersed coal dust. Addition of about 10 percent sodium chloride to the permissible formulations reduced the probability of igniting coal dust very significantly. Bundled explosive charges were more incendive than the equivalent column charges.

14. Van Dolah, R. W., F. C. Gibson, and J. N. Murphy. Further Studies on Sympathetic Detonations. BuMines Rept. of Inv. 6903, 1966, 35 pp.

Concern over the proper location of AN-FO mixing plants and the location of raw ammonium nitrate with respect to the mixed blasting agents led the Bureau to investigate sympathetic detonation distances for these materials. Field experiments were conducted with missile- and non-missile-producing AN-FO donors weighing up to 5,400 pounds and acceptors of the same size. The usual cube-root scaling law was not confirmed. For AN, exponents for the relationship $S = F(W^x)$ were 0.51 with non-missile-producing donors and 0.61 for missile-producing donors (S = distance for sympathetic detonation, W = weight of explosive). For AN-FO, an exponent of 0.80 appears indicated for missile-producing donors; AN-FO in polyethylene bags appeared to initiate somewhat more easily than bulk AN-FO. Sand-filled barricades between the donor and the acceptor reduced the value of S by 1/3 to 1/7. Experiments with 1,600-pound missile-producing AN-FO donors and the same weight of dynamite acceptors indicated that initiation would occur in 50 percent of shots at 167 feet. With nonmissile donors the corresponding distance was 67 feet.

PART 3.--SENSITIVITY OF HYDROGEN PEROXIDE TO SHOCK INITIATION

A comparative study was made of the shock sensitivities of 86 percent and 90.7 percent hydrogen peroxide at temperatures from 5° to 70° C. The effect of container diameter and temperature was also observed. Experiments were performed in passivated 16-inch 61ST6 aluminum cups with inside diameters (id) of 0.5, 0.82, 1.05, 1.25, and 1.61 inches. A 1.63-inch-diameter tetryl donor weighing 51 grams was used for initiation in all cases.

With 86 percent H_2O_2 at zero gap in 1.61-inch-id cups, detonation velocities of about 5,600 meters per second were observed at and above 50° C. However, no detonations were observed in smaller (1.05- and 1.25-inch-id) containers at temperatures from 25° to 70° C.

With 90.7 percent H_2O_2, detonations were observed in all cup diameters. In these tests detonations were observed at zero gap as follows: in 0.50-inch-id cups at a minimum temperature of 70° C; in 0.82-inch-id cups at a minimum temperature of 55° C; in 1.05-inch-id cups at a minimum temperature of 35° C; in 1.25-inch-id cups and in 1.61-inch-id cups at a minimum temperature of 25° C. Gap values increased with increasing temperature (fig. 3). Detonation velocities ranged from 5,500 to 6,000 meters per second.

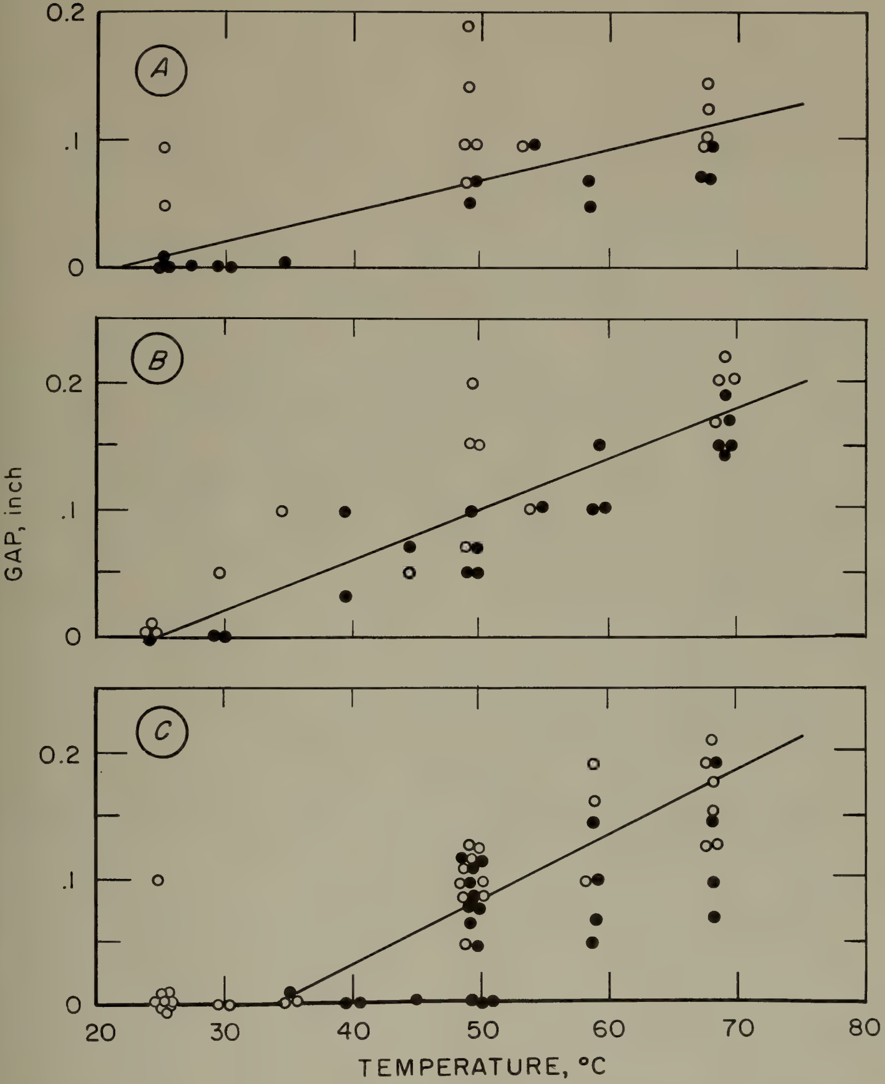

FIGURE 3. - Shock Sensitivity of 90.7 Percent H_2O_2 in 61ST6 Aluminum Cups 16 Inches Long. *A*, 1.61-inch id; *B*, 1.25-inch id; and *C*, 1.05-inch id. Open circles represent negative results, closed circles represent positive results.

The effect of container diameter as a function of temperature is compared for 86 percent and 90.7 percent H_2O_2 in figure 4. The critical diameters for 86 percent and 90.7 percent H_2O_2 may be estimated from a line of demarcation between positive and negative results. For 90.7 percent H_2O_2, the apparent critical diameter decreased from approximately 1.6 to 0.8 inches as the temperature increased from 25° to 70° C. For 86 percent H_2O_2, the critical diameter appears to be about 1.6 inches at 50° C and to decrease to about 1.4 inches at 70° C.

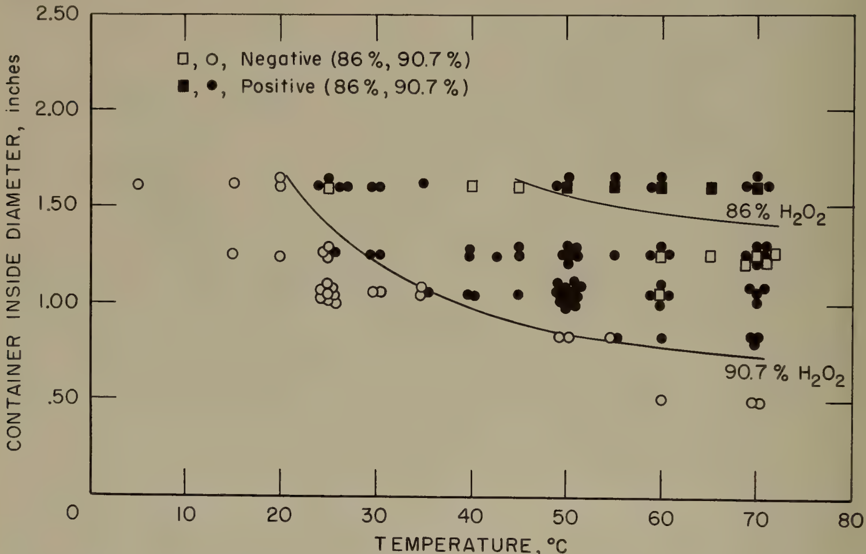

FIGURE 4. - Effect of Temperature and Cup Diameter on Shock Initiation in the H_2O_2-H_2O System in Aluminum Tubes.

IC bureau of mines information circular 8388

HELIUM-4 EXPERIMENTAL PVT REFERENCES: 1895 TO 1968

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

August 1968

HELIUM-4 EXPERIMENTAL PVT REFERENCES: 1895 TO 1968

By Robert E. Barieau

* * * * * * * * * * * information circular 8388

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CONTENTS

HELIUM-4 EXPERIMENTAL PVT REFERENCES: 1895 TO 1968

by

Robert E. Barieau[1]

ABSTRACT

A list of 163 references to original experimental PVT data on helium is presented for the period 1895 to 1968. The list is complete as of the start of the Helium Centennial Year, 1968, to the best of the author's knowledge. Citations were keypunched for easy updating and are listed alphabetically by author.

INTRODUCTION

In connection with our project on the critical evaluation of thermodynamic data on helium, we have prepared a list of 163 references, arranged alphabetically by author, to original experimental PVT data on helium. The references were keypunched on cards for computer listing which eliminates the necessity of retyping the list when bringing it up-to-date. As far as I know, the list is complete as of the start of the Helium Centennial Year, 1968.

The list contains only references to original experimental data, including theses. Published articles resulting from theses are also included. Tabulation of PVT properties calculated from equations of state are omitted. References to P-T data for two-phase equilibrium are also omitted from this listing.

Practically all experimenters who use the Burnett method to obtain PVT data on gases make measurements on helium to obtain the volume ratio of their apparatus. Papers containing such data on helium are listed even though the title does not indicate such data exist.

Authors' names and initials are given as they appear in the original article. Material translated from the original language is given between parentheses. When an English translation of a paper is known to exist, it is also cited.

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[1] Supervisory research chemist, project leader, Thermodynamics, Helium Research Center, Bureau of Mines, Amarillo, Tex.

Early Leiden University articles were usually published first in Dutch by the Royal Academy of Science of Amsterdam. The Academy later published English or French translations. Still later, the University published the articles in English or French as a Leiden Communication. All publications of a single Leiden article are given but are listed as a single reference.

It would be appreciated if any errors or omissions are brought to the author's attention.

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UNITED STATES DEPARTMENT OF THE INTERIOR

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Forrest T. Moyer [1] and Nina L. Jones [2]

GENERAL INJURY EXPERIENCE

Injury experience in the coal-mining industry was worse in 1965 as both the frequency and severity rates of injuries increased 2 and 6 percent, respectively, over comparable data for 1964 (tables 1-8). The retrogression in the safety record during 1965 resulted from the less favorable record at bituminous-coal mines, which more than offset the improved injury experience at anthracite mines. The 259 fatal and 11,138 nonfatal injuries occurred at a rate of 45.77 per million man-hours of exposure and resulted in a severity rate of 8,960 days lost per million man-hours. Although the number of fatalities was the second lowest annual total in the recorded history, it was 17 higher than in 1964. At anthracite operations the total of 8 fatalities in 1965 was the lowest annual figure in statistical history. The annual numbers of nonfatal injuries at all coal mines and the resulting rates of occurrence have varied little in the past 5 years (table 1).

The total days lost from all injuries rose from 2.13 million in 1964 to 2.23 million in 1965 (table 5). Fatal and permanent total injuries, with a standard time charge of 6,000 days each, accounted for 1,650,000 days; permanent partial injuries, 191,932 days; and temporary total disabilities, 388,911 days. The severity rate for fatal injuries was 6,241, 8 percent higher than in 1964, and the nonfatal severity rate of 2,718 days lost per million man-hours was 2 percent higher than in the preceding year. The average severity of permanent partial injuries was 730, or 48 days fewer per injury than in 1964. The average days lost for each temporary total injury was 36 days in each year.

The 259 fatalities in 1965 occurred in 219 mines, 2 percent of the total number of active operations (tables 7 and 8). These mines with fatal injuries employed 19 percent of the workforce, produced 21 percent of the total output, and had 23 percent of all nonfatal injuries.

1/ Chief, Branch of Accident Analysis.
2/ Statistical officer.
Both authors are with the Branch of Accident Analysis, Division of Accident Prevention and Health, Bureau of Mines, Washington, D. C.

The average number of men working daily in all coal mines and their aggregate worktime were each 1 percent lower than in 1964. However, production of coal rose 4 percent owing to the gain in productivity. The tons produced per man-day have increased by approximately 1 ton in each of the last 5 years and reached 16.75 tons in 1965.

Nearly 528 million tons of bituminous coal, lignite, and anthracite were mined from 9,151 mines during the year (table 2). Of the total, 338 million tons (64 percent) came from underground workings; 172 million (33 percent) from strip pits; 14 million (3 percent) from bituminous-coal auger mines; 3 million (0.6 percent) from anthracite culm banks; and 0.7 million (0.1 percent) from anthracite dredges. Eighty percent of the total working force was employed at underground mines for an average of 209 days during the year. Productivity at underground mines increased to 1.71 from 1.64 tons per man-hour in 1964. The rate of production increased in all types of mining except at anthracite culm bank operations. Overall productivity from all mines in 1965 was 2.12 tons per man-hour compared with 2.00 in 1964.

Bituminous-Coal and Lignite Mines

A total of 10,322 injuries occurred in the bituminous-coal and lignite industry at a rate of 44.37 per million man-hours of exposure (table 3). Compared with data for 1964, the number of injuries and the rate of occurrence each were 4 percent higher.

Work-connected fatalities in the industry increased 33 (15 percent) to a total of 251. These occurred at a rate of 1.08 per million man-hours, 15 percent over the 1964 rate. Nonfatal disabilities totaled 10,071 in 1965, 4 percent above the previous year and resulted in a rate of 43.30, 3 percent higher than in 1964.

Worktime lost or charged against all injuries was 2.15 million days compared with 1.93 million in 1964. Due to the increased number of fatalities, the average severity of all injuries rose from 194 days in 1964 to 208 days in 1965. However, permanent partial injuries averaged 752 days per injury compared with 766 in 1964 and temporary total injuries averaged 37 days compared with 38 in the previous year.

The average number of men working was relatively unchanged from the preceding year--137,602 in 1965 compared with 137,617 in 1964. Active days increased from 212 to 213 and worktime increased slightly to 232.6 million man-hours. The average work-year increased 4 hours to 1,690 hours in 1965.

Output of bituminous-coal and lignite gained 5 percent to 513 million tons in 1965. The rate of production (tons per man-hour) increased at both underground and surface mines and the total of 2.21 tons per man-hour was 5 percent over the preceding year.

There were 8,208 mines in operation, 133 fewer than in 1964. The count of underground mines was 181 less and the auger mines count was 11 less than in the previous year, but stripping operations increased 59 in number.

Pennsylvania Anthracite Mines

The safety record of the Pennsylvania anthracite industry was improved in 1965 as both the frequency and severity rates of all injuries declined. A total 1,075 work injuries resulted in a frequency rate of 65.65 per million man-hours compared with 1,366 injuries in 1964 that occurred at a rate of 67.07. The severity rate of 4,936 for all injuries represented a 49-percent improvement over that of 9,650 in 1964.

There was a sharp improvement in the fatality record and the 1965 total of eight work-deaths was an alltime low. The fatality frequency rate of 0.49 per million man-hours was 58 percent lower than in 1964 and was far below that of any other year in statistical history.

The 1,067 nonfatal injuries were 275 (20 percent) fewer than in 1964. However, owing to a decline of similar proportions in man-hours of exposure, the frequency rate of 65.16 was only 1 percent below that of the previous year.

Total days lost or charged against all injuries was 80,823, of which 48,000 was charged to fatal injuries, 2,310 to permanent partial disabilities, and 30,513 to temporary total injuries. The average severity for all injuries was 75 days per injury, compared with 144 in the preceding year. Permanent partial cases had an average time charge of 210 days and for temporary total disabilities the time lost per injury was 29 days in 1965.

Average employment of 11,132 was 15 percent below 1964 and these men worked an average of 204 days in 1965 or 10 less than in the preceding year. As a result, man-hours of work dropped 20 percent from 20.4 million to 16.4 million, and total production declined 15 percent from 17.5 million tons to 14.9 million. The productivity rate (ton per man-hour) increased from 0.86 in 1964 to 0.91 in 1965.

GENERAL INJURY FACTORS

The injury and employment information reported for 1965 has been analyzed and classified by common factors or elements related to the accidents which resulted in work injuries (tables 9-17). The analysis and classification provide summarized industrywide injury experience. The distribution of injuries by and within these factors shows where and how the injury-causing accidents occurred. The relative prevalence of injuries to the different parts of body, the nature of injury, and the relative severity of injuries are among the summarized factors.

Causes

Falls of roof, rib, and face material continued to cause the most deaths in the coal-mining industry (table 9). In 1965, 131 underground fatalities--59 percent of the total underground and 51 percent of the grand total--resulted from these causes. Also in underground workings, 8 (57 percent) of the 14 permanent total disabilities resulted from falls of roof or face accidents. A classification by detailed cause (table 12) which gives the activity of the injured worker, revealed that 24 percent of the fatal and 22 percent of the nonfatal injuries from falls of roof or face occurred during loading activities. Fatal injuries from falls of roof and face while setting or pulling props and while operating or moving continuous mining machines, each had the next highest incidence of 23 fatal injuries during these work activities. All told, 59 percent of the fatal and 39 percent of the nonfatal injuries from falls of roof or face material occurred during the three named work activities. In addition to the underground accidents resulting from falls of face or side, two fatal and 26 nonfatal injuries occurred at strip mines and one fatal and one nonfatal injury occurred at auger mines.

The second leading cause of fatal injuries was haulage with underground accidents accounting for 35 deaths. Above-ground haulage accidents resulted in seven fatalities all of which were to surface employees at underground mines. Accidents while operating or moving machinery (27) were the third highest cause of death at all coal mines--14 occurred underground, five at surface operations, and eight at stripping operations.

The four ranking causes of nonfatal disabilities at all work locations resulted in 8,475 injuries, 76 percent of the total. The causes with the respective number of injuries were as follows: Handling materials, 2,671; haulage, 2,215; machinery, 1,837; and falls of roof or face, 1,752. Under the materials handling category, the largest number of injuries for specific materials occurred while handling props, ties, and timber.

Of the four leading causes of nonfatal injuries, the most severe disabilities resulted from falls of roof, face, or rib with an average of 95 days lost or charged to each injury. Nonfatal disabilities from haulage and machinery accidents each averaged 84 days per injury; for handling materials accidents the average was 29 days. A total of 584,102 days (86 percent of the total time lost for nonfatal injuries) was charged to the above four causes.

The total number of injuries by major cause are shown separately for the bituminous-coal and anthracite industries in figure 1.

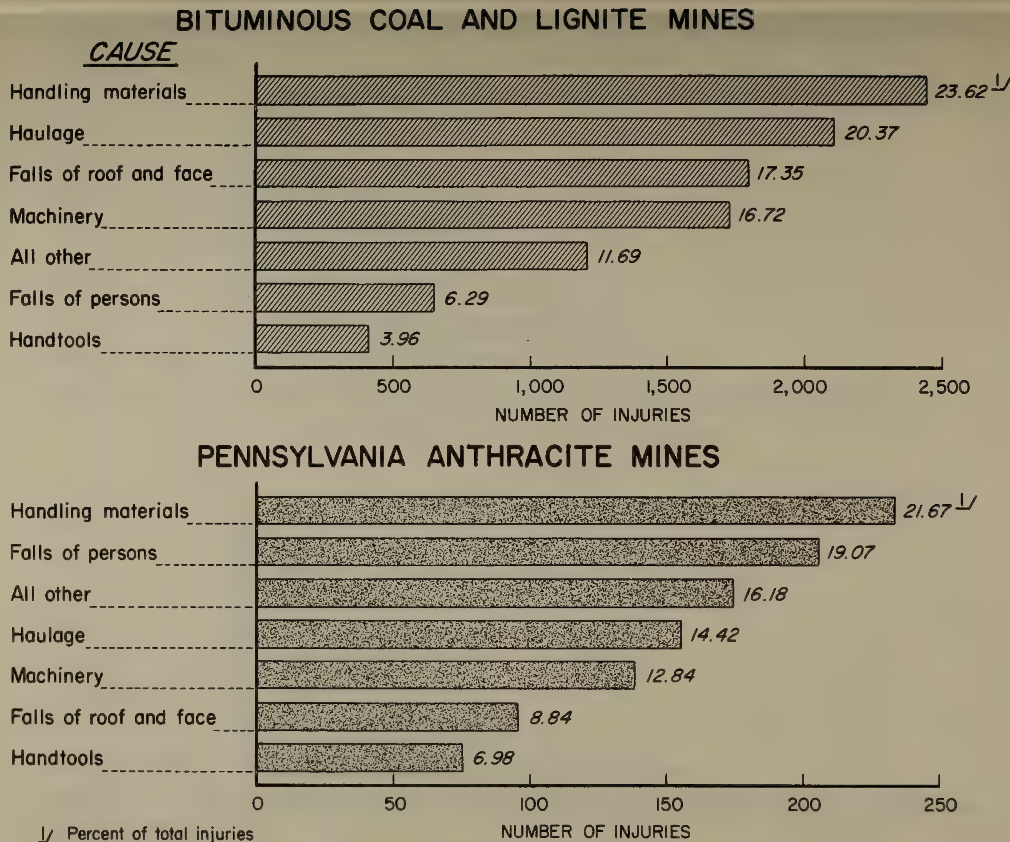


FIGURE 1. - Distribution of Injuries by Major Cause, 1965.

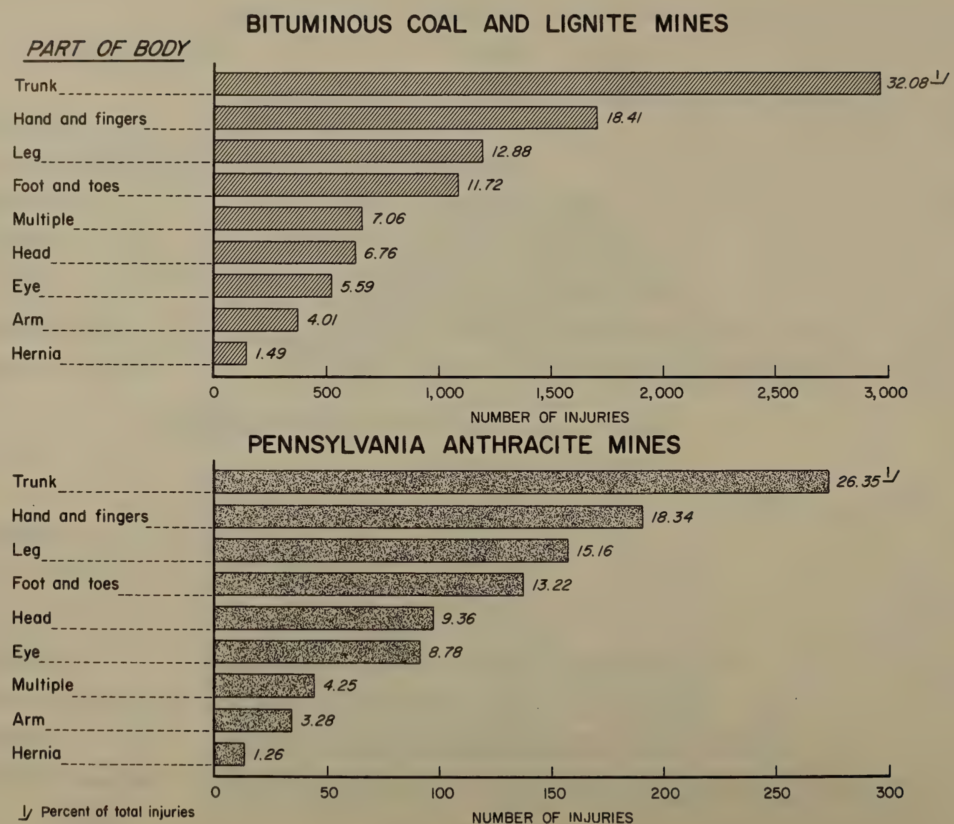


FIGURE 2. - Distribution of Injuries by Part of Body Injured, 1965. (Does not include 1,071 injuries in bituminous coal and 39 injuries in anthracite mines for which part of body was not stated.)

Part of Body Injured

The distribution of injuries by the body part affected, in figure 2, shows the trunk, hand and fingers, leg, and foot and toes in decreasing order, to be the parts most frequently injured in both bituminous-coal and anthracite mines. More detailed distributions of the data by work location are given in tables 13 and 14. The tabular data include the average severity of injuries to the different parts of the body.

Part of Body Injured and Cause

For the first time in this series of publications, injuries by extent of disability have been related to the part of body by major cause of accident (table 15). Accidents from falls of roof, face, or rib accounted for 27 fatal, one permanent total, two permanent partial, and 113 temporary total injuries to the head. Similar types of accidents--pressure bumps or bursts and inrush of water and materials--resulted in three fatal and four temporary total disabilities to the head. These four causes represented 59 percent of the total fatal injuries to the head, 100 percent of the permanent injuries, and 18 percent of the temporary total disabilities.

Injuries to the eye were caused most frequently by machinery (138), handtools (119), and handling material (108) accidents. Six permanent partial injuries (all in bituminous coal) resulting in loss of sight in one eye were caused as follows: Handtools, three, and haulage, explosives, and machinery, one each. Accidents involving flying particles or fragments from a particular activity or from equipment in operation are included in each major cause category.

The highest number of nonfatal disabilities to the trunk (1,013 or 32 percent of the total) were caused by handling materials. The interrelationship of this cause of accident with the trunk suggests improper lifting or handling procedures resulting in back strains and sprains. Thirty-eight (58 percent) of the fatal injuries to the trunk and 6 (50 percent) of the permanent total injuries resulted from falls of roof, face, or rib material.

Fifty-eight percent of the injuries resulting in inguinal hernia were caused by handling material accidents. It would appear that there is a need for more education in proper lifting and handling of heavy objects.

Haulage and machinery accidents accounted for 54 percent of the injuries to the arms. Eleven of the 13 permanent partial injuries and 208 of the 392 temporary total disabilities to the arms were charged to these two causes.

Seventy-five percent (147) of the 196 permanent partial injuries to the hand and fingers resulted from accidents involving machinery and haulage equipment. Temporary total disabilities from these two causes accounted for

42 percent of the total for this degree of injury. However, the greatest number of injuries to hands and fingers from a single cause was 448 temporary and 22 permanent partial disabilities which resulted from handling material accidents.

Accidents involving haulage equipment caused two fatal, one permanent total, four permanent partial, and 300 temporary total injuries to the leg. Also, five permanent partial, and 211 temporary total injuries to the leg resulted from machinery accidents. These two causal factors accounted for 39 percent of the total injuries to the leg.

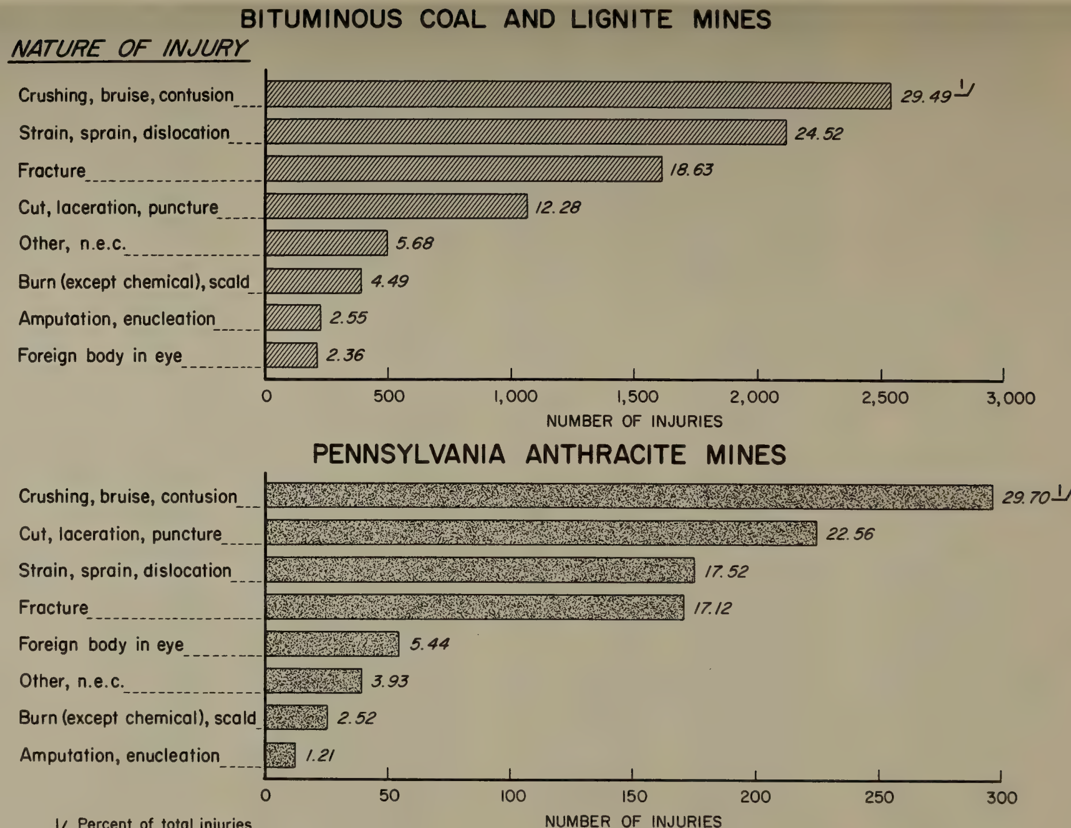
Seventeen of the 21 permanent partial injuries to the foot and toes were charged to haulage and machinery accidents, while 422 (35 percent) of the temporary total injuries were also attributable to these causes. The third highest cause of accident to the foot and toes was handling materials with 238 temporary total and 1 permanent partial.

Of the 138 fatal injuries charged to multiple parts of the body, 68 (49 percent) resulted from falls of roof or face material as did 33 percent of the nonfatal injuries.

Nature of Injury

Data on nature of injury categories, combined for both bituminous coal and anthracite mines shows the largest number of injuries, 2,831, to be bruises and contusions (including crushing). This category was followed by sprains, strains, and dislocations with 2,283 injuries, and fractures with 1,772 injuries. These three categories accounted for 72 percent of all injuries for which the nature was stated.

Nature of injury data are shown separately for the bituminous coal and anthracite industries in figure 3 and in more detail by work location and average severity in tables 16 and 17.



1/ Percent of total injuries

FIGURE 3. - Distribution of Injuries by Nature of Injury, 1965. (Does not include 1,722 injuries in bituminous coal and 82 injuries in anthracite mines for which nature of injury was not stated.

Disability Distribution of Temporary Total Injuries

The distribution of temporary total injuries for which the company reported days lost are shown by days of disability per injury and general work location in tables 18 and 19. For all coal mines, 85 percent of all temporary total injuries were closed with company reported days of disability. Twenty-eight percent (2,597) of these were of 5 days or less duration, while 9 percent (867) disabled the worker for 91 days or more.

OTHER INJURY FACTORS

Coal mines may be classified and distributed within selected common factors of operating conditions. Within such factors as degree of mechanization, thickness of bed, and others, the distribution of mines summarizes the effects of variations in operating conditions on injury experience. Further, such classification enables a more detailed comparison of the safety record of an individual mine with the group record of similar mines in the industry (tables 18-37).

As operating conditions in bituminous-coal and anthracite mines differ widely, the distribution of mines with common elements are presented separately for each industry.

Bituminous-Coal and Lignite Mines

Mechanical Loading

The degree of mechanical loading was reported by 87 percent of the underground bituminous-coal mines (tables 20 and 22). Mechanical loading is considered to be 100 percent at strip and auger mines.

The group of mines, where all coal was hand loaded, accounted for 21 percent of the workforce and 68 percent of the number of mines for which the information was stated. Over 31 million tons of coal was produced at the rate of 1.14 tons per man-hour. Injuries occurred at the rate of 43.81 per million man-hours of exposure and the average severity of all injuries was 209 days per injury.

Total mechanized loading was reported for 29 percent of the mines which employed three-fourths of the workforce. Almost 292 million tons of coal was produced at the rate of 1.98 tons per man-hour. In these mines, injuries occurred at the rate of 50.42 per million man-hours and the average severity was 213 days per injury.

Employment Size

Injury experience and employment data by employment-size groups are shown in table 24. For the purpose of comparison, the deep mines are combined into two groups, those with 19 men or less and those with 20 men or more.

In mines employing less than 20 men, 69 fatal and 1,675 nonfatal injuries occurred at frequency rates of 1.80 and 43.77, respectively. Employment at these mines represented 28 percent of the total at underground mines; man-hours, 21 percent; and production, 15 percent. Coal was produced at the rate of 1.33 tons per man-hour.

Twelve percent of the total deep mines employed 20 men or more (72 percent of the workforce) and produced 282 million tons of coal in 145 million man-hours, or 1.95 tons per man-hour. The fatal frequency rate at these mines was 1.11 per million man-hours, while nonfatal disabilities occurred at the rate of 49.83.

The highest productivity rate at strip mines (5.27 tons per man-hour) was at 31 mines employing 100 men or more. Injury experience at these mines was worse than in any other size group; fatalities occurred at the rate of 0.71 per million man-hours and nonfatal disabilities at 33.06. There were no fatalities at the 397 mines in the group employing five to nine men whereas the other size groups had from 1 to 7 fatalities. Nonfatal-injury experience was best at the mines in the 10-19 employee group for which the frequency rate was 17.62.

The highest occurrence of injuries (46.52) at auger mines was in the group employing from one to four men at 235 operations; the highest productivity rate, 7.33 tons per man-hour, was also for this group. The safest operations were the 113 mines employing from five to nine men; the injury frequency was 17.73 per million man-hours and productivity was 5.66 tons per man-hour.

Length of Shift

Injury and employment data by length of shift are shown in table 26. Ninety-three percent of the deep mines were worked an average of 7.93 hours per shift, 73 percent of the strip mines averaged 7.95 hours, and 71 percent of the auger mines averaged 8.00 hours per shift. Since such large majorities of the mines fall within the 7.5 to 8.4 hour shifts, comparisons of the injury and employment data are not made.

Number of Shifts

As shown in table 28, 88 percent (5,457) of the underground mines were worked one shift a day to produce 57.6 million tons of coal at the rate of 1.18 tons per man-hour. The 550 mines working two shifts a day produced 132 million tons of coal at the rate of 1.90 tons per man-hour, while 202 mines working three shifts produced 139.6 million tons at the rate of 2.04 tons per man-hour. The highest rate of injury occurrence was in the mines working two shifts a day. Seventy-three percent of the strip mines and 92 percent of the auger mines were worked one shift a day. The highest productivity, 4.42 tons per man-hour, was from strip mines working three shifts a day, while auger mines working two shifts a day had the highest rate, 7.23 tons per man-hour.

Days Active

Fifty-five percent of the total coal tonnage from deep mines was produced at a rate of 1.84 tons per man-hour from the 1,881 underground mines which had an average of 200 to 249 active days. The overall safety record for these mines was 47.58 injuries per million man-hours worked, the second best of the underground mine groupings by number of days active. The most favorable safety record was an overall rate of 43.68 for mines that were in operation 100 to 149 days.

Thickness of Bed

Of the underground mines for which thickness of bed was given, the highest rate of occurrence for both fatal and nonfatal injuries was in mines from 25 to 36 inches thick (table 32). The respective frequency rates per million man-hours of exposure were 1.67 for fatalities and 59.18 for nonfatal injuries. These mines represented 35 percent of the underground mines. The best overall safety record was in mines less than 25 inches thick, however, this group represented only 110 mines and produced less than 500,000 tons.

Production Size

Injury experience by production-size groups is shown in table 34. The 80 underground mines producing 1 million or more tons each during the year had the best safety record (35.96 injuries per million man-hours) and the highest productivity rate (2.21 tons per man-hour). Strip and auger mines producing from 25,000 to 49,999 tons had the lowest rate of injury occurrence, 16.90 and 20.04, respectively.

Pennsylvania Anthracite Mines

Mechanical Loading

Information on percentage of coal loaded mechanically was reported for 67 percent of the underground anthracite mines (table 21). Of these, operators of 352 mines (82 percent) reported all coal was hand loaded. Thirty-four percent of the deep-mine workforce was employed in these mines and they produced 30 percent of the coal at a rate of 0.67 ton per man-hour. Injuries occurred at the rate of 41.09 per million man-hours, the lowest for any of the groups.

One-hundred percent mechanical loading was reported for only 10 percent of the deep mines, however 52 percent of the working force was employed in these mines and they accounted for 58 percent of the tonnage. The productivity rate of 0.63 ton per man-hour was slightly lower than in the all hand loaded group. Injuries occurred at a rate of 126.03 per million man-hours--the third highest rate of any of the groups.

Employment Size

In 95 percent of the underground mines, less than 20 men were employed per mine (table 25). Employment at these mines represented 44 percent of the deep-mine workforce and output was 43 percent of the total. Coal was produced at the rate of 0.70 ton per man-hour. Although 63 percent of the fatal injuries was reported in these operations, they accounted for only 15 percent of the non-fatal injuries.

Thirty underground mines employed an average of 20 men or more and accounted for 56 percent of the total deep-mine employment. More than 3 million tons of coal were produced at a rate of 0.61 ton per man-hour. Injuries occurred at the rate of 125.88 per million man-hours compared with 34.91 in the group employing less than 20 men.

The best safety record (24.36 injuries per million man-hours) for strip mines was attained by workers in 39 mines which employed from five to nine men each. Thirty-three mines employing from 10 to 19 men had the worst record--59.41 injuries per million man-hours. Productivity in these two groups was 1.36 and 1.71 tons per man-hour, respectively.

Forty-nine percent (51 banks) of the culm bank operations employed from 1 to 4 men each. Injuries occurred at the rate of 19.04 per million man-hours, the lowest recorded for any of the size groups.

Of the 14 dredges operating during the year, 13 were injury free. The only disability recorded was at a dredge employing from 50 to 99 men.

The larger preparation plants had the worst safety records--64.04 injuries per million man-hours for those employing from 20 to 49 men and 63.95 for those employing from 50 to 99 men.

Length of Shift

As shown in table 27, 72 percent of the underground mines were classed in the 6.5 to 7.4 hour group and these mines were operated an average of 7.16 hours per shift. Similarly, 72 percent of the strip mines fell in one group and were worked an average of 7.03 hours per shift.

Number of Shifts

From table 29, it was noted that 94 percent of the underground mines and 60 percent of the strip mines were worked one shift per day.

Days Active

Table 31 shows injury experience and employment data by days-active groupings. The largest number of underground mines (137) were classed in the 200 to 249 day group and had an average of 229 days active. Two fatal and 541

nonfatal injuries occurred in these mines at respective rates of 0.41 and 112.09 per million man-hours. The combined rate of 112.50 was much higher than in any of the other groups. Twenty-five percent of the strip mines were worked from 200 to 249 days during the year; the average for the group was 234 days. Injuries at these mines occurred at a rate of 36.07 per million man-hours or 10 percent lower than the 40.28 recorded for all strip mines.

Thickness of Bed

A review of the data in table 33 revealed that the highest rate of injury occurrence was in mines with bed thickness of 109 inches or more while the best safety record was in mines with 73 to 84 inch seams.

Production Size

From table 35, it was noted that 95 percent of the underground mines, 72 percent of the strip pits, and 68 percent of the culm banks were classed in the group producing 25,000 tons or less during the year.

INJURY EXPERIENCE BY STATE

Reports on coal-mining activity were received from operations in 28 States (tables 38-42). Disabling injuries in or around the mines were reported by operators in 24 of these States (table 38). Fatal injuries were reported in bituminous-coal mines of 12 States and in the Pennsylvania anthracite industry. The lowest rate of occurrence of fatalities was in the anthracite mines, 0.49 per million man-hours, and the highest was in Colorado with 4.18 deaths per million man-hours.

No disabling injuries were reported from mines in California, Oregon, Arizona, and South Dakota where a total of 18 men was employed at two underground mines and two stripping operations. Of the States in which nonfatal injuries occurred, the frequency of occurrence ranged from 13.28 per million man-hours for mines in Texas to 82.57 in Washington mines.

The leading State in bituminous-coal production was West Virginia which accounted for 29 percent of the total tonnage and 22 percent of the total number of mines. Of the national bituminous-coal workforce, 32 percent was employed in West Virginia mines (table 39). Kentucky, the second highest producer with 17 percent of the Nation's output, had the largest number of active mines during the year (23 percent of the total). Other breakdowns of injury and employment data by State are found in tables 40, 41, and 42.

MAJOR DISASTERS, 1956-65

During 1965, three major disasters occurred in the coal-mining industry--all at bituminous-coal mines. Twenty-one persons were killed, 14 in

two explosions and seven in a mine fire. There were no major disasters in 1964 (table 43).

A major disaster, as defined for the mineral industries, is a single accident in which five or more employees lost their lives. There were 19 disasters in the 10-year period, 1956-65, killing 267 men. However, 1956 and 1964 were free of disasters. The only disaster for the anthracite industry during the 10-year period resulted from an inrush of water which killed 12 men. Fourteen of the remaining 18 disasters resulted from explosions of gas or dust in underground bituminous-coal mines. A total of 219--86 percent of the total for bituminous coal--was killed in these accidents. Two mine fires accounted for 25 deaths; one fall of roof, for six; and a fall of face resulting from a bump, for five.

OFFICEWORKERS

A total of 3,514 onsite officeworkers were reported to have worked more than 6 million man-hours during an average of 226 days during the year (table 44). One fatal injury at a West Virginia mine and one temporary total disability in the Pennsylvania anthracite industry resulted in an injury rate of 0.32 per million man-hours.

HISTORICAL DATA

Injury experience, employment and worktime data for the bituminous coal, Pennsylvania anthracite, and total coal-mining industries are shown for 1930-65 in tables 45-47. The man-hour data for the years 1930-44 have been converted to a portal-to-portal basis. Hence, the injury-frequency and the productivity rates are directly comparable for each year.

Historical information on fatalities in the coal-mining industry are given in tables 49-52. Figures from 1910 through 1965 represent the entire industry, while those prior to 1910 cover only the States that maintained records of fatal injuries.

The fatality rate per thousand employees at all coal mines was 1.74 for the 5-year period 1961-65, or a rise of 4 percent compared with the rate of 1.68 for the previous 5-year period. The rate of 2.57 deaths per thousand 300-day workers was the same for both 5-year periods. Owing to the sharply rising trend in productivity, the number of fatal injuries per million tons of coal mined decreased 28 percent--from 0.81 for the 1956-60 period to 0.58 for the 1961-65 period.

Fatalities by major cause since 1906 are shown separately for the bituminous-coal and anthracite industries in tables 49 and 50, respectively. The corresponding percentage distribution of fatalities by major cause is shown in tables 51 and 52. In the statistical history of coal mining, the leading cause of fatalities has been falls of roof and face. On a 5-year average for 1961-65, deaths from this cause continued to represent nearly half of all fatalities.

ACKNOWLEDGMENTS

The Bureau of Mines gratefully acknowledges the cooperation of the coal-mining companies and State mining officials in supplying details on injuries and related employment and production data, which have made possible the presentation of comparable injury statistics for the industry in 1965.

Special acknowledgment is extended to Mary B. McNair and staff of the Fuels Section of the Branch of Accident Analysis, Bureau of Mines, for the collection and compilation of data and the preparation of the statistical tables contained in this report.

SCOPE OF STUDY

To keep the mineral and allied industries informed of trends in the causes of accidents and to point out the need for corrective measures, the Bureau of Mines collects, analyzes, and periodically publishes health and safety statistics. This report includes data for 1965 on injury experience, with related employment statistics, at coal mines in the United States.

Description of Data

Information in this publication was compiled from reports furnished by producers on two questionnaires of the Bureau of Mines: Form 6-1420, "Employer's Report of Coal-Mine Injury," and Form 6-1420A and B, "Coal-Mine Injuries and Employment." Injury and employment data cover all men at an operation who are engaged in production, development, maintenance, and repair work, including supervisory and technical personnel. Proprietors and firm members working at the establishment also are included. Data on officeworkers at the mine or plant are included in one set of data in table 1 and are detailed by State in table 47. The officeworker data are excluded from all other tables. Information on cokeworkers and employees in stores or affiliated industries other than coal production are excluded. The companies are requested to report actual man-hours and man-days of work on active and inactive days. Man-hour information is reported on a portal-to-portal basis, which includes work, travel, and lunch. The average number of days active is calculated by dividing the average number of men working daily into the reported man-days of work.

Data on injuries come from the analysis of descriptive reports of each disabling injury as provided by the producers. A disabling injury is one that causes death, permanent impairment, or the loss of work for more than the remainder of the day on which the accident occurred.

Days of disability for temporary total injuries are determined by counting calendar days beginning with the day following the date of injury and ending with the day before the employee returns to work. Permanent partial, permanent total, and fatal injuries are charged with days of disability according to the standard scale of time charges of the American Standards Association, Inc., (now United States of America Standards Institute), Z16.1, revised 1954 (reaffirmed 1959), pages 7-8.

Definition of Terms

To eliminate the lengthy repetition of explanatory footnotes on tables, the following definitions are given for terms used in headings and/or stubs:

Men at work.--Average number of men at work each day mine was active. As absenteeism and labor turnover are considered, this number is lower than the number available for work as measured by a count of names on the payroll.

Frequency rates.--Per million man-hours--the number of injuries multiplied by 1 million divided by the man-hours; per million short tons--the number of injuries multiplied by 1 million divided by the tons. Where rates are shown for total injuries (fatal and nonfatal), they may differ from the sums of the component rates, because all rates are calculated separately.

Severity rates.--The number of days charged multiplied by 1 million divided by the man-hours. All fatalities and permanent total disabilities have a standard time-loss charge of 6,000 days.

Average severity.--The number of days charged divided by the number of injuries.

Degree of injury.--Permanent total disability, permanent partial disability, and temporary total disability.

Permanent total disability.--The loss of, or loss of use of, both or any two of the following: Hands, arms, legs, feet, or eyes; or any other nonfatal injury that permanently and totally incapacitates the injured person from following any gainful occupation.

Permanent partial disability.--Any nonfatal injury that permanently but only partially disables a worker. Includes the total or partial loss of, or loss of use of, an arm, hand, leg, finger(s), eye, hearing, etc., even though no time was lost.

Temporary total disability.--Any nonfatal injury that does not result in permanent impairment, but that renders the injured persons unable to perform a regularly established job that is open and available to him during the entire time interval corresponding to the hours of his regular shift on any one or more days (including Sundays, days off, or plant shutdown) subsequent to the day of injury.

Distribution of all injuries, percent.--The number of injuries for which the subject heading was not stated is excluded in calculating the percentage of distribution. All percentages are calculated separately and therefore do not necessarily add to 100 percent.

TABLE 1. - Salient statistics on injuries, injury rates, employment, production, and productivity at coal mines in the United States, 1961-65

	Including officeworkers					Excluding officeworkers				
	1961	1962	1963	1964	1965	1961	1962	1963	1964	1965
BITUMINOUS-COAL MINES										
Number of injuries:										
Fatal	275	263	252	218	252	275	263	252	218	251
Nonfatal	9,902	9,783	9,838	9,728	10,071	9,902	9,783	9,838	9,728	10,071
Total	10,177	10,046	10,090	9,946	10,323	10,177	10,046	10,090	9,946	10,322
Injury rates:										
Frequency per million man-hours:										
Fatal	1.16	1.13	1.06	0.92	1.06	1.18	1.15	1.09	0.94	1.08
Nonfatal	41.61	41.94	41.53	41.10	42.24	42.52	42.86	42.38	41.92	43.30
Frequency per million tons:										
Fatal	.68	.62	.55	.45	.49	.68	.62	.55	.45	.49
Nonfatal	24.56	23.14	21.37	19.93	19.63	24.56	23.14	21.37	19.93	19.63
Severity per million man-hours:										
Fatal	6,933	6,765	6,383	5,526	6,342	7,085	6,913	6,513	5,637	6,474
Nonfatal	2,635	2,739	2,275	2,623	2,701	2,692	2,799	2,321	2,675	2,769
Severity per million tons:										
Fatal	4,092	3,732	3,285	2,680	2,947	4,092	3,732	3,285	2,680	2,935
Nonfatal	1,555	1,511	1,171	1,272	1,255	1,555	1,511	1,171	1,272	1,255
Average severity, days lost per injury:										
Permanent partial	585	666	774	766	752	585	666	774	766	752
Temporary total	39	36	33	38	37	39	36	33	38	37
All injuries	224	221	203	194	209	224	221	203	194	208
Men working daily	154,692	150,047	146,621	140,111	140,837	151,776	147,276	143,628	137,617	137,[illegible]02
Man-hours worked	237,978,457	233,251,720	236,878,375	236,698,123	238,414,264	232,871,317	228,266,613	232,136,275	232,036,853	232,613,020
Production ------------short tons	403,222,152	422,838,427	460,285,437	488,085,932	513,083,704	403,222,152	422,838,427	460,285,437	488,085,932	513,083,704
Productivity:										
Tons per man-hour	1.69	1.81	1.94	2.06	2.15	1.73	1.85	1.98	2.10	2.21
Tons per man-day	13.40	14.34	15.40	16.39	17.12	13.69	14.65	15.72	16.72	17.55
ANTHRACITE MINES										
Number of injuries:										
Fatal	19	26	32	24	8	19	26	32	24	8
Nonfatal	1,295	1,161	1,295	1,342	1,068	1,295	1,161	1,295	1,342	1,067
Total	1,314	1,187	1,327	1,366	1,076	1,314	1,187	1,327	1,366	1,075
Injury rates:										
Frequency per million man-hours:										
Fatal	.82	1.22	1.48	1.15	.48	.85	1.26	1.52	1.18	.49
Nonfatal	56.16	54.65	60.01	64.39	63.50	57.75	56.14	61.53	65.89	65.16
Frequency per million tons:										
Fatal	1.09	1.52	1.74	1.37	.54	1.09	1.52	1.74	1.37	.54
Nonfatal	73.97	67.76	70.60	76.74	71.63	73.97	67.76	70.60	76.74	71.57
Severity per million man-hours:										
Fatal	4,944	7,343	8,897	6,910	2,854	5,084	7,544	9,122	7,070	2,931
Nonfatal	2,546	1,827	3,165	2,522	1,954	2,618	1,877	3,245	2,580	2,004
Severity per million tons:										
Fatal	6,512	9,105	10,467	8,235	3,219	6,512	9,105	10,467	8,235	3,219
Nonfatal	3,353	2,266	3,724	3,006	2,204	3,353	2,266	3,724	3,006	2,202
Average severity, days lost per injury:										
Permanent partial	967	593	1,022	931	210	967	593	1,022	931	210
Temporary total	27	29	27	25	29	27	29	27	25	29
All injuries	131	164	196	144	75	131	164	196	144	75
Men working daily	16,167	14,366	13,855	13,473	11,411	15,792	14,010	13,498	13,144	11,132
Man-hours worked	23,059,896	21,245,235	21,579,768	20,840,284	16,819,078	22,424,285	20,679,762	21,048,233	20,307,697	16,375,359
Production ------------short tons	17,506,825	17,133,399	18,343,910	17,486,876	14,909,337	17,506,825	17,133,399	18,343,910	17,486,876	14,909,337
Productivity:										
Tons per man-hour	.76	.81	.85	.84	.89	.78	.83	.87	.86	.91
Tons per man-day	5.51	5.86	6.16	6.09	6.56	5.65	6.01	6.30	6.22	6.56
ALL COAL MINES										
Number of injuries:										
Fatal	294	289	284	242	260	294	289	284	242	259
Nonfatal	11,197	10,944	11,133	11,070	11,139	11,197	10,944	11,133	11,070	11,138
Total	11,491	11,233	11,417	11,312	11,399	11,491	11,233	11,417	11,312	11,397
Injury rates:										
Frequency per million man-hours:										
Fatal	1.13	1.14	1.10	.94	1.02	1.15	1.16	1.12	.96	1.04
Nonfatal	42.89	43.00	43.07	42.98	43.64	43.86	43.96	43.97	43.86	44.73
Frequency per million tons:										
Fatal	.70	.66	.59	.48	.49	.70	.66	.59	.48	.49
Nonfatal	26.61	24.87	23.26	21.90	21.10	26.61	24.87	23.26	21.90	21.09
Severity per million man-hours:										
Fatal	6,758	6,813	6,593	5,638	6,112	6,910	6,965	6,730	5,753	6,241
Nonfatal	2,627	2,663	2,349	2,615	2,652	2,686	2,722	2,398	2,668	2,718
Severity per million tons:										
Fatal	4,193	3,941	3,560	2,872	2,955	4,193	3,941	3,560	2,872	2,943
Nonfatal	1,630	1,540	1,268	1,332	1,282	1,630	1,540	1,268	1,332	1,282
Average severity, days lost per injury:										
Permanent partial	605	663	790	778	730	605	663	790	778	730
Temporary total	38	35	33	36	36	38	35	33	36	36
All injuries	213	215	202	188	196	213	215	202	188	196
Men working daily	170,859	164,413	160,476	153,584	152,248	167,568	161,286	157,126	150,761	[illegible]
Man-hours worked	261,038,353	254,496,955	258,458,143	257,538,407	255,233,342	255,295,602	248,946,375	253,184,508	252,404,550	[illegible]
Production ------------short tons	420,728,977	439,971,826	478,629,347	505,572,808	527,993,041	420,728,977	439,971,826	478,629,347	505,572,808	[illegible]
Productivity:										
Tons per man-hour	1.61	1.73	1.85	1.96	2.07	1.65	1.77	1.89	2.00	[illegible]
Tons per man-day	12.64	13.57	14.56	15.48	16.34	12.93	13.87	14.86	15.79	[illegible]

TABLE 2. - Employment, production, and productivity (short tons per man-hour) data on coal mines in the United States, by kind of coal and general work location, 1965

	Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour	Number of mines
Bituminous-coal mines:							
Underground mines:							
Underground	91,982	207	19,059,078	153,021,285	332,670,834	2.17	6,229
Surface	21,669	218	4,727,369	35,731,720	-----------	----	-----
Total or average	113,651	209	23,786,447	188,753,005	332,670,834	1.76	6,229
Strip mines	21,865	236	5,167,356	41,480,190	166,127,499	4.00	1,582
Auger mines	2,086	138	288,132	2,379,825	14,285,371	6.00	397
Total or average	137,602	213	29,241,935	232,613,020	513,083,704	2.21	8,208
Pennsylvania anthracite mines:							
Underground mines:							
Underground	4,501	202	907,491	6,443,993	5,306,215	.82	637
Surface	1,572	218	343,212	2,489,882	-----------	----	-----
Total or average	6,073	206	1,250,703	8,933,875	5,306,215	.59	637
Strip mines	2,349	217	510,072	3,624,873	5,965,481	1.65	188
Culm banks	566	119	67,346	485,904	2,937,184	6.04	104
Dredges	97	247	23,912	192,575	700,457	3.64	14
Preparation plants	2,047	205	419,169	3,138,132	-----------	----	-----
Total or average	11,132	204	2,271,202	16,375,359	14,909,337	.91	943
All coal mines:							
Underground mines:							
Underground	96,483	207	19,966,569	159,465,278	337,977,049	2.12	6,866
Surface	23,241	218	5,070,581	38,221,602	-----------	----	-----
Total or average	119,724	209	25,037,150	197,686,880	337,977,049	1.71	6,866
Strip mines	24,214	234	5,677,428	45,105,063	172,092,980	3.82	1,770
Auger mines	2,086	138	288,132	2,379,825	14,285,371	6.00	397
Culm banks	566	119	67,346	485,904	2,937,184	6.04	104
Dredges	97	247	23,912	192,575	700,457	3.64	14
Preparation plants	2,047	205	419,169	3,138,132	-----------	----	-----
Total or average	148,734	212	31,513,137	248,988,379	527,993,041	2.12	9,151

TABLE 3. - Injury experience at bituminous-coal mines in the United States, by general work location, 1965

	Underground mines			Strip mines	Auger mines	Total
	Underground	Surface	Total			
Number of injuries:						
Fatal	215	17	232	18	1	251
Nonfatal:						
Permanent total	14	1	15	1	-	16
Permanent partial	199	25	224	27	1	252
Temporary total	7,738	983	8,721	1,004	78	9,803
Total nonfatal	7,951	1,009	8,960	1,032	79	10,071
Grand total	8,166	1,026	9,192	1,050	80	10,322
Days lost:						
Fatal	1,290,000	102,000	1,392,000	108,000	6,000	1,506,000
Nonfatal:						
Permanent total	84,000	6,000	90,000	6,000	-----	96,000
Permanent partial	142,982	23,040	166,022	22,460	1,140	189,622
Temporary total	298,903	31,831	330,734	25,072	2,592	358,398
Total nonfatal	525,885	60,871	586,756	53,532	3,732	644,020
Grand total	1,815,885	162,871	1,978,756	161,532	9,732	2,150,020
Frequency rates:						
Per million man-hours:						
Fatal	1.41	.48	1.23	.43	.42	1.08
Nonfatal	51.96	28.24	47.47	24.88	33.20	43.30
All injuries	53.37	28.71	48.70	25.31	33.62	44.37
Per million tons:						
Fatal	.65	-------	.70	.11	.07	.49
Nonfatal	23.90	-------	26.93	6.21	5.53	19.63
All injuries	24.55	-------	27.63	6.32	5.60	20.12
Severity rates:						
Per million man-hours:						
Fatal	8,430	2,855	7,375	2,604	2,521	6,474
Nonfatal	3,437	1,704	3,109	1,291	1,568	2,769
All injuries	11,867	4,558	10,483	3,894	4,089	9,243
Per million tons:						
Fatal	3,878	-------	4,184	650	420	2,935
Nonfatal	1,581	-------	1,764	322	261	1,255
All injuries	5,459	-------	5,948	972	681	4,190
Average severity:						
Permanent partial	719	922	741	832	1,140	752
Temporary total	39	32	38	25	33	37
All injuries	222	159	215	154	122	208

TABLE 4. - Injury experience at Pennsylvania anthracite mines, by general work location, 1965

	Underground mines			Strip mines	Culm banks	Dredges	Preparation plants	Total
	Underground	Surface	Total					
Number of injuries:								
Fatal	8	-----	8	-----	-----	----	-----	8
Nonfatal:								
Permanent total	------	-----	------	-----	-----	----	-----	------
Permanent partial	8	-----	8	-----	-----	----	3	11
Temporary total	692	45	737	146	13	1	159	1,056
Total nonfatal	700	45	745	146	13	1	162	1,067
Grand total	708	45	753	146	13	1	162	1,075
Days lost:								
Fatal	48,000	-----	48,000	-----	-----	----	-----	48,000
Nonfatal:								
Permanent total	------	-----	------	-----	-----	----	-----	------
Permanent partial	1,690	-----	1,690	-----	-----	----	620	2,310
Temporary total	20,046	1,554	21,600	3,520	331	28	5,034	30,513
Total nonfatal	21,736	1,554	23,290	3,520	331	28	5,654	32,823
Grand total	69,736	1,554	71,290	3,520	331	28	5,654	80,823
Frequency rates:								
Per million man-hours:								
Fatal	1.24	-----	.90	-----	-----	----	-----	.49
Nonfatal	108.63	18.07	83.39	40.28	26.75	5.19	51.62	65.16
All injuries	109.87	18.07	84.29	40.28	26.75	5.19	51.62	65.65
Per million tons:								
Fatal	1.51	-----	1.51	-----	-----	----	-----	.54
Nonfatal	131.92	-----	140.40	24.47	4.43	1.43	-----	71.57
All injuries	133.43	-----	141.91	24.47	4.43	1.43	-----	72.10
Severity rates:								
Per million man-hours:								
Fatal	7,449	-----	5,373	-----	-----	----	-----	2,931
Nonfatal	3,373	624	2,607	971	681	145	1,802	2,004
All injuries	10,822	624	7,980	971	681	145	1,802	4,936
Per million tons:								
Fatal	9,046	-----	9,046	-----	-----	----	-----	3,219
Nonfatal	4,096	-----	4,389	590	113	40	-----	2,202
All injuries	13,142	-----	13,435	590	113	40	-----	5,421
Average severity:								
Permanent partial	211	-----	211	-----	-----	----	207	210
Temporary total	29	35	29	24	25	28	32	29
All injuries	98	35	95	24	25	28	35	75

TABLE 5. - Injury experience at all coal mines in the United States, by general work location, 1965

	Underground mines			Strip mines	Auger mines	Culm banks	Dredges	Preparation plants	Total
	Underground	Surface	Total						
Number of injuries:									
Fatal	223	17	240	18	1	-----	----	-----	259
Nonfatal:									
Permanent total	14	1	15	1	-----	-----	----	-----	16
Permanent partial	207	25	232	27	1	-----	----	3	263
Temporary total	8,430	1,028	9,458	1,150	78	13	1	159	10,859
Total nonfatal	8,651	1,054	9,705	1,178	79	13	1	162	11,138
Grand total	8,874	1,071	9,945	1,196	80	13	1	162	11,397
Days lost:									
Fatal	1,338,000	102,000	1,440,000	108,000	6,000	-----	----	-----	1,554,000
Nonfatal:									
Permanent total	84,000	6,000	90,000	6,000	-----	-----	----	-----	96,000
Permanent partial	144,672	23,040	167,712	22,460	1,140	-----	----	620	191,932
Temporary total	318,949	33,385	352,334	28,592	2,592	331	28	5,034	388,911
Total nonfatal	547,621	62,425	610,046	57,052	3,732	331	28	5,654	676,843
Grand total	1,885,621	164,425	2,050,046	165,052	9,732	331	28	5,654	2,230,843
Frequency rates:									
Per million man-hours:									
Fatal	1.40	.44	1.21	.40	.42	-----	----	-----	1.04
Nonfatal	54.25	27.58	49.09	26.12	33.20	26.75	5.19	51.62	44.73
All injuries	55.65	28.02	50.31	26.52	33.62	26.75	5.19	51.62	45.77
Per million tons:									
Fatal	.66	-------	.71	.10	.07	-----	----	-----	.49
Nonfatal	25.60	-------	28.71	6.85	5.53	4.43	1.43	-----	21.09
All injuries	26.26	-------	29.43	6.95	5.60	4.43	1.43	-----	21.59
Severity rates:									
Per million man-hours:									
Fatal	8,391	2,669	7,284	2,394	2,521	-----	----	-----	6,241
Nonfatal	3,434	1,633	3,086	1,265	1,568	681	145	1,802	2,718
All injuries	11,825	4,302	10,370	3,659	4,089	681	145	1,802	8,960
Per million tons:									
Fatal	3,959	-------	4,261	628	420	-----	----	-----	2,943
Nonfatal	1,620	-------	1,805	332	261	113	40	-----	1,282
All injuries	5,579	-------	6,066	959	681	113	40	-----	4,225
Average severity:									
Permanent partial	699	922	723	832	1,140	-----	----	207	730
Temporary total	38	32	37	25	33	25	28	32	36
All injuries	212	154	206	138	122	25	28	35	196

TABLE 6. - Number of injuries and frequency and severity rates at coal mines in the United States, by degree of injury, 1965

Degree of injury	Bituminous-coal mines			Pennsylvania anthracite mines			All coal mines		
	Number of injuries	Injury rates		Number of injuries	Injury rates		Number of injuries	Injury rates	
		Frequency	Severity		Frequency	Severity		Frequency	Severity
Fatal	251	1.08	6,474	8	0.49	2,931	259	1.04	6,241
Permanent total	16	.07	413	-----	-----	-----	16	.06	386
Permanent partial	252	1.08	815	11	0.67	141	263	1.06	771
Temporary total	9,803	42.14	1,541	1,056	64.49	1,863	10,859	43.61	1,562
Total nonfatal injuries	10,071	43.30	2,769	1,067	65.16	2,004	11,138	44.73	2,718
All injuries	10,322	44.37	9,243	1,075	65.65	4,936	11,397	45.77	8,960

TABLE 7. - Comparative fatal- and nonfatal-injury data on bituminous-coal mines in the United States, 1965

	Mines reporting fatal injuries	Mines reporting no fatal injuries	All bituminous-coal mines
Number of mines	210	7,998	8,208
Production ---- short tons	112,577,141	400,506,563	513,083,704
Proportion of total tonnage ---- percent	21.9	78.1	100.0
Number of employees	26,782	110,820	137,602
Proportion of total employees ---- percent	19.5	80.5	100.0
Number of employees per mine	128	14	17
Man-days worked	6,541,519	22,700,416	29,241,935
Average days worked per man	244	205	213
Man-hours worked	52,028,701	180,584,319	232,613,020
Average hours worked per man	1,943	1,630	1,690
Production per man-hour ---- tons	2.16	2.22	2.21
Number of fatalities	251	----	251
Number of nonfatal injuries	2,351	7,720	10,071
Fatality rate per million man-hours	4.82	----	1.08
Nonfatal-injury rate per million man-hours	45.19	42.75	43.30

TABLE 8. - Comparative fatal- and nonfatal-injury data on Pennsylvania anthracite mines, 1965

	Mines reporting fatal injuries	Mines reporting no fatal injuries	All anthracite mines
Number of mines	9	934	943
Production ---- short tons	859,694	14,049,643	14,909,337
Proportion of total tonnage ---- percent	6.0	94.0	100.0
Number of employees	1,068	10,064	11,132
Proportion of total employees ---- percent	9.6	90.4	100.0
Number of employees per mine	119	11	12
Man-days worked	229,484	2,041,718	2,271,202
Average days worked per man	215	203	204
Man-hours worked	1,683,038	14,692,321	16,375,359
Average hours worked per man	1,576	1,460	1,471
Production per man-hour ---- ton	.51	.96	.91
Number of fatalities	8	---	8
Number of nonfatal injuries	185	882	1,067
Fatality rate per million man-hours	4.75	---	.49
Nonfatal-injury rate per million man-hours	109.92	60.03	65.16

TABLE 9. - Number of injuries at coal mines in the United States, by principal causes of injury, kind of coal, and general work location, 1965

Principal causes of injury	Bituminous-coal mines		Pennsylvania anthracite mines		All coal mines	
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal
Underground mines:						
Underground:						
Falls of roof	119	1,369	2	21	121	1,390
Falls of face or rib	7	261	3	67	10	328
Pressure bumps or bursts	2	12	-	7	2	19
Inrush of water and material	---	-----	2	---	2	-----
Other falling objects	1	131	-	68	1	199
Falls of persons	---	313	-	133	---	446
Handling materials	---	1,790	-	147	---	1,937
Handtools	---	285	-	49	---	334
Stepping on objects	---	169	-	27	---	196
Striking or bumping	---	41	-	2	---	43
Haulage	34	1,612	1	75	35	1,687
Explosions (gas or dust)	15	15	-	5	15	20
Explosives	1	89	-	6	1	95
Electricity	4	304	-	6	4	310
Machinery	14	1,387	-	78	14	1,465
Suffocation	---	4	-	---	---	4
Mine fires	11	30	-	---	11	30
All other	---	101	-	3	---	104
Total	208	7,913	8	694	216	8,607

TABLE 9. - Number of injuries at coal mines in the United States, by principal causes of injury, kind of coal, and general work location, 1965--Continued

Principal causes of injury	Bituminous-coal mines		Pennsylvania anthracite mines		All coal mines	
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal
Underground mines--Continued						
Shaft and slope:						
Falls of roof ----------	---	2	-	1	---	3
Falls of face or rib ----------	---	1	-	---	---	1
Other falling objects ----------	2	-----	-	---	2	-----
Falls of persons ----------	1	18	-	---	1	18
Handling materials ----------	---	7	-	---	---	7
Handtools ----------	---	3	-	---	---	3
Stepping on objects ----------	---	1	-	3	---	4
Haulage ----------	---	4	-	2	---	6
Explosions (gas or dust) ----------	4	-----	-	---	4	-----
Machinery ----------	---	1	-	---	---	1
All other ----------	---	1	-	---	---	1
Total ----------	7	38	-	6	7	44
Surface:						
Falls or slides of coal or overburden ----------	---	3	-	---	---	3
Other falling objects ----------	1	17	-	---	1	17
Falls of persons ----------	1	133	-	6	1	139
Handling materials ----------	---	321	-	15	---	336
Handtools ----------	---	56	-	4	---	60
Stepping on objects ----------	---	27	-	---	---	27
Haulage ----------	7	287	-	10	7	297
Explosions (gas or dust) ----------	---	5	-	---	---	5
Explosives ----------	---	1	-	---	---	1
Electricity ----------	2	22	-	1	2	23
Machinery ----------	5	88	-	7	5	95
Fires ----------	---	8	-	---	---	8
All other ----------	1	41	-	2	1	43
Total ----------	17	1,009	-	45	17	1,054
Total, underground mines ----------	232	8,960	8	745	240	9,705
Strip mines:						
Falls or slides of coal or overburden ----------	2	25	-	1	2	26
Other falling objects ----------	1	15	-	7	1	22
Falls of persons ----------	2	175	-	32	2	207
Handling materials ----------	---	295	-	29	---	324
Handtools ----------	---	61	-	8	---	69
Stepping on objects ----------	---	24	-	2	---	26
Striking or bumping ----------	---	1	-	---	---	1
Haulage ----------	---	154	-	25	---	179
Explosives ----------	1	10	-	3	1	13
Electricity ----------	3	8	-	---	3	8
Machinery ----------	8	190	-	28	8	218
Fires ----------	---	7	-	---	---	7
All other ----------	1	67	-	11	1	78
Total ----------	18	1,032	-	146	18	1,178
Auger mines:						
Falls or slides of coal or overburden ----------	1	1	-	---	1	1
Other falling objects ----------	---	1	-	---	---	1
Falls of persons ----------	---	6	-	---	---	6
Handling materials ----------	---	25	-	---	---	25
Handtools ----------	---	4	-	---	---	4
Stepping on objects ----------	---	1	-	---	---	1
Haulage ----------	---	4	-	---	---	4
Machinery ----------	---	33	-	---	---	33
All other ----------	---	4	-	---	---	4
Total ----------	1	79	-	---	1	79
Culm banks ----------	---	-----	-	13	---	13
Dredges ----------	---	-----	-	1	---	1
Preparation plants ----------	---	-----	-	162	---	162
Grand total ----------	251	10,071	8	1,067	259	11,138

TABLE 10. - Days of disability from injuries at coal mines in the United States, by principal causes of injury, kind of coal, and general work location, 1965

Principal causes of injury	Bituminous-coal mines		Pennsylvania anthracite mines		All coal mines	
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal
Underground mines:						
Underground:						
Falls of roof	714,000	137,052	12,000	2,126	726,000	139,178
Falls of face or rib	42,000	21,174	18,000	3,769	60,000	24,943
Pressure bumps or bursts	12,000	569	------	712	12,000	1,281
Inrush of water and material	---------	-------	12,000	------	12,000	-------
Other falling objects	6,000	3,818	------	2,858	6,000	6,676
Falls of persons	---------	17,199	------	2,930	---------	20,129
Handling materials	---------	54,865	------	3,100	---------	57,965
Handtools	---------	11,592	------	548	---------	12,140
Stepping on objects	---------	4,959	------	366	---------	5,325
Striking or bumping	---------	941	------	30	---------	971
Haulage	204,000	154,871	6,000	2,435	210,000	157,306
Explosions (gas or dust)	90,000	701	------	119	90,000	820
Explosives	6,000	6,969	------	32	6,000	7,001
Electricity	24,000	3,838	------	103	24,000	3,941
Machinery	84,000	103,462	------	2,081	84,000	105,543
Suffocation	---------	40	------	------	---------	40
Mine fires	66,000	374	------	------	66,000	374
All other	---------	2,005	------	19	---------	2,024
Total	1,248,000	524,429	48,000	21,228	1,296,000	545,657
Shaft and slope:						
Falls of roof	---------	150	------	300	---------	450
Falls of face or rib	---------	1	------	------	---------	1
Other falling objects	12,000	-------	------	------	12,000	-------
Falls of persons	6,000	984	------	------	6,000	984
Handling materials	---------	156	------	------	---------	156
Handtools	---------	71	------	------	---------	71
Stepping on objects	---------	11	------	18	---------	29
Haulage	---------	81	------	190	---------	271
Explosions (gas or dust)	24,000	-------	------	------	24,000	-------
Machinery	---------	1	------	------	---------	1
All other	---------	1	------	------	---------	1
Total	42,000	1,456	------	508	42,000	1,964
Total, underground	1,290,000	525,885	48,000	21,736	1,338,000	547,621
Surface:						
Falls or slides of coal or overburden	---------	89	------	------	---------	89
Other falling objects	6,000	618	------	------	6,000	618
Falls of persons	6,000	4,594	------	105	6,000	4,699
Handling materials	---------	9,535	------	427	---------	9,962
Handtools	---------	1,210	------	179	---------	1,389
Stepping on objects	---------	436	------	------	---------	436
Haulage	42,000	19,569	------	722	42,000	20,291
Explosions (gas or dust)	---------	279	------	------	---------	279
Explosives	---------	48	------	------	---------	48
Electricity	12,000	423	------	6	12,000	429
Machinery	30,000	21,211	------	82	30,000	21,293
Fires	---------	101	------	------	---------	101
All other	6,000	2,758	------	33	6,000	2,791
Total	102,000	60,871	------	1,554	102,000	62,425
Total, underground mines	1,392,000	586,756	48,000	23,290	1,440,000	610,046
Strip mines:						
Falls or slides of coal or overburden	12,000	2,156	------	16	12,000	2,172
Other falling objects	6,000	1,122	------	231	6,000	1,353
Falls of persons	12,000	5,043	------	544	12,000	5,587
Handling materials	---------	6,825	------	238	---------	7,063
Handtools	---------	2,653	------	90	---------	2,743
Stepping on objects	---------	398	------	7	---------	405
Striking or bumping	---------	25	------	------	---------	25
Haulage	---------	4,297	------	1,375	---------	5,672
Explosives	6,000	464	------	6	6,000	470
Electricity	18,000	352	------	------	18,000	352
Machinery	48,000	23,311	------	663	48,000	23,974
Fires	---------	233	------	------	---------	233
All other	6,000	6,653	------	350	6,000	7,003
Total	108,000	53,532	------	3,520	108,000	57,052

TABLES 10. - Days of disability from injuries at coal mines in the United States, by principal causes of injury, kind of coal, and general work location, 1965--Continued

Principal causes of injury	Bituminous-coal mines		Pennsylvania anthracite mines		All coal mines	
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal
Auger mines:						
Falls or slides of coal or overburden	6,000	5	------	------	6,000	5
Other falling objects	---------	48	------	------	---------	48
Falls of persons	---------	152	------	------	---------	152
Handling materials	---------	926	------	------	---------	926
Handtools	---------	54	------	------	---------	54
Stepping on objects	---------	31	------	------	---------	31
Haulage	---------	101	------	------	---------	101
Machinery	---------	2,404	------	------	---------	2,404
All other	---------	11	------	------	---------	11
Total	6,000	3,732	------	------	6,000	3,732
Culm banks	---------	-------	------	331	---------	331
Dredges	---------	-------	------	28	---------	28
Preparation plants	---------	-------	------	5,654	---------	5,654
Grand total	1,506,000	644,020	48,000	32,823	1,554,000	676,843

TABLE 11. - Average severity of all injuries at coal mines in the United States, by principal causes of injury, kind of coal, and general work location, 1965

Principal causes of injury	Bituminous-coal mines	Pennsylvania anthracite mines	All coal mines
Underground mines:			
Underground:			
Falls of roof	572	614	573
Falls of face or rib	236	311	251
Pressure bumps or bursts	898	102	632
Inrush of water and material	-----	6,000	6,000
Other falling objects	74	42	63
Falls of persons	55	22	45
Handling materials	31	21	30
Handtools	41	11	36
Stepping on objects	29	14	27
Striking or bumping	23	15	23
Haulage	218	111	213
Explosions (gas or dust)	3,023	24	2,595
Explosives	144	5	135
Electricity	90	17	89
Machinery	134	27	128
Suffocation	10	-----	10
Mine fires	1,619	-----	1,619
All other	20	6	19
All causes	218	99	209
Shaft and slope:			
Falls of roof	75	300	150
Falls of face or rib	1	-----	1
Other falling objects	6,000	-----	6,000
Falls of persons	368	-----	368
Handling materials	22	-----	22
Handtools	24	-----	24
Stepping on objects	11	6	7
Haulage	20	95	45
Explosions (gas or dust)	6,000	-----	6,000
Machinery	1	-----	1
All other	1	-----	1
All causes	966	85	862
All causes, underground	222	98	212

TABLE 11. - Average severity of all injuries at coal mines in the United States, by principal causes of injury, kind of coal, and general work location, 1965--Continued

Principal causes of injury	Bituminous-coal mines	Pennsylvania anthracite mines	All coal mines
Underground mines--Continued			
Surface:			
Falls or slides of coal or overburden	30	-----	30
Other falling objects	368	-----	368
Falls of persons	79	18	76
Handling materials	30	28	30
Handtools	22	45	23
Stepping on objects	16	-----	16
Haulage	209	73	205
Explosions (gas or dust)	56	-----	56
Explosives	48	-----	48
Electricity	518	6	497
Machinery	551	12	513
Fires	13	-----	13
All other	209	17	200
All causes	159	35	154
All causes, underground mines	215	95	206
Strip mines:			
Falls or slides of coal or overburden	524	16	506
Other falling objects	445	33	320
Falls of persons	96	17	84
Handling materials	23	8	22
Handtools	43	11	40
Stepping on objects	17	4	16
Striking or bumping	25	-----	25
Haulage	28	55	32
Explosives	588	2	462
Electricity	1,668	-----	1,668
Machinery	360	24	318
Fires	33	-----	33
All other	186	32	165
All causes	154	24	138
Auger mines:			
Falls or slides of coal or overburden	3,003	-----	3,003
Other falling objects	48	-----	48
Falls of persons	25	-----	25
Handling materials	37	-----	37
Handtools	14	-----	14
Stepping on objects	31	-----	31
Haulage	25	-----	25
Machinery	73	-----	73
All other	3	-----	3
All causes	122	-----	122
Culm banks	-----	25	25
Dredges	-----	28	28
Preparation plants	-----	35	35
Average, all causes	208	75	196

TABLE 12. - Number and average severity of injuries at coal mines in the United States, by kind of coal, detailed causes of injury, general work location, and degree of injury, 1965

Causes of injury and general work location	Bituminous-coal mines							Pennsylvania anthracite mines							All coal mines						
	Number of injuries				Average severity			Number of injuries				Average severity			Number of injuries				Average severity		
	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries
UNDERGROUND MINES																					
Underground:																					
Falls of roof:																					
While mining	12	3	4	223	2,100	56	458	-	-	-	5	---	157	157	12	3	4	228	2,100	58	452
While loading	25	2	3	287	377	57	566	1	-	-	6	---	176	1,008	26	2	3	293	377	59	576
While testing or taking down roof	6	-	-	74	-----	55	501	-	-	-	--	---	---	-----	6	-	-	74	-----	55	501
While setting or pulling timber or props	23	-	-	133	-----	69	944	-	-	-	10	---	28	28	23	-	-	143	-----	66	888
While preparing or installing roof bolts	3	-	1	253	150	39	109	-	-	-	--	---	---	-----	3	-	1	253	150	39	109
While moving machinery from one working place to another	5	1	-	25	-----	73	1,220	1	-	-	--	---	---	6,000	6	1	-	25	-----	73	1,370
While moving or placing cars in active working places	1	-	-	5	-----	86	1,071	-	-	-	--	---	---	-----	1	-	-	5	-----	86	1,071
While moving, setting up, or operating continuous-mining machines	22	1	-	111	-----	78	1,095	-	-	-	--	---	---	-----	22	1	-	111	-----	78	1,095
All other	22	1	7	235	296	61	583	-	-	-	--	---	---	-----	22	1	7	235	296	61	583
Falls of roof or face material from pressure bumps or bursts	2	-	-	12	-----	47	898	-	-	-	7	---	102	102	2	-	-	19	-----	67	632
Falls of face or rib:																					
While mining	1	-	2	61	2,350	40	205	1	-	1	52	50	58	168	2	-	3	113	1,583	48	188
While loading	5	-	1	68	70	66	467	-	-	-	5	---	106	106	5	-	1	73	70	69	444
While testing or taking down roof	--	-	-	6	-----	14	14	-	-	-	--	---	---	-----	--	-	-	6	-----	14	14
While setting or pulling timbers or props	--	-	1	18	325	58	72	2	-	-	7	---	19	1,348	2	-	1	25	325	47	482
While preparing or installing roof bolts	--	-	1	29	300	61	69	-	-	-	--	---	---	-----	--	-	1	29	300	61	69
While moving machinery from one working place to another	--	-	2	6	200	106	130	-	-	-	--	---	---	-----	--	-	2	6	200	106	130
While moving or placing cars in active working places	--	-	-	---	-----	---	-----	-	-	-	2	---	25	25	--	-	-	2	-----	25	25
While moving, setting up, or operating continuous-mining machines	1	-	1	9	300	64	625	-	-	-	--	---	---	-----	1	-	1	9	300	64	625
All other	--	-	-	56	-----	72	72	-	-	-	--	---	---	-----	--	-	-	56	-----	72	72
Inrush of water and material	--	-	-	---	-----	---	-----	2	-	-	--	---	---	6,000	2	-	-	---	-----	---	6,000
Other falling materials or objects:																					
Props or timbers	--	-	-	31	-----	19	19	-	-	-	11	---	102	102	--	-	-	42	-----	41	41
Objects dropped or thrown by coworker	--	-	-	8	-----	36	36	-	-	-	--	---	---	-----	--	-	-	8	-----	36	36
Rolling, shifting, or sliding material	--	-	1	52	150	27	30	-	-	1	20	200	20	29	--	-	2	72	175	25	29
Falling equipment or machinery under repair	1	-	1	10	235	25	540	-	-	-	--	---	---	-----	1	-	1	10	235	25	540
Rushes, rolls, or slides of coal or rock	--	-	-	12	-----	31	31	-	-	-	36	---	32	32	--	-	-	48	-----	31	31
All other	--	-	-	16	-----	32	32	-	-	-	--	---	---	-----	--	-	-	16	-----	32	32
Slips or falls of persons:																					
On same level:																					
While escaping another hazard	--	-	-	19	-----	22	22	-	-	-	3	---	150	150	--	-	-	22	-----	39	39
While handling materials	--	1	-	118	-----	29	80	-	-	-	52	---	20	20	--	1	-	170	-----	26	61
From handtools slipping or breaking	--	-	-	8	-----	64	64	-	-	-	--	---	---	-----	--	-	-	8	-----	64	64
Caused by electric current	--	-	-	5	-----	18	18	-	-	-	--	---	---	-----	--	-	-	5	-----	18	18
While operating or moving machinery	--	-	-	34	-----	37	37	-	-	-	11	---	8	8	--	-	-	45	-----	30	30
All other	--	-	-	105	-----	44	44	-	-	-	43	---	13	13	--	-	-	148	-----	35	35
From an elevation:																					
While escaping another hazard	--	-	-	1	-----	40	40	-	-	-	1	---	17	17	--	-	-	2	-----	29	29
While handling materials	--	-	-	5	-----	43	43	-	-	-	9	---	13	13	--	-	-	14	-----	24	24
While operating or moving machinery	--	-	-	10	-----	44	44	-	-	-	2	---	35	35	--	-	-	12	-----	43	43
Due to failure of scaffolds, ladders, etc.	--	-	-	2	-----	5	5	-	-	-	5	---	106	106	--	-	-	7	-----	77	77
All other	--	-	-	5	-----	21	21	-	-	-	7	---	12	12	--	-	-	12	-----	16	16
Handling materials:																					
Props, ties, or timbers	--	-	6	414	235	27	30	-	-	-	54	---	17	17	--	-	6	468	235	26	29
Coal	--	-	-	190	-----	29	29	-	-	-	50	---	29	29	--	-	-	240	-----	29	29
Rock or slate	--	-	-	171	-----	31	31	-	-	-	8	---	32	32	--	-	-	179	-----	31	31
Rails	--	-	4	120	145	34	37	-	-	-	3	---	5	5	--	-	4	123	145	33	36
Wire or wire ropes	--	-	-	99	-----	32	32	-	-	-	4	---	11	11	--	-	-	103	-----	31	31
Roof-bolting materials	--	-	-	19	-----	19	19	-	-	-	1	---	41	41	--	-	-	20	-----	20	20
Handling, moving, or installing conveyor pans	--	-	1	64	100	32	33	-	-	-	7	---	16	16	--	-	1	71	100	30	31
Flying particles while loading car of coal, rock, or gob	--	-	-	3	-----	10	10	-	-	-	2	---	11	11	--	-	-	5	-----	10	10
Flying particles while handling all other material	--	-	-	46	-----	11	11	-	-	-	9	---	5	5	--	-	-	55	-----	10	10
All other	--	-	7	646	267	29	32	-	-	-	9	---	22	22	--	-	7	655	267	29	32

TABLE 12. - Number and average severity of injuries at coal mines in the United States, by kind of coal, detailed causes of injury, general work location, and degree of injury, 1965--Continued

Causes of injury and general work location	Bituminous-coal mines							Pennsylvania anthracite mines							All coal mines						
	Number of injuries				Average severity			Number of injuries				Average severity			Number of injuries				Average severity		
	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries
UNDERGROUND MINES--Continued																					
Underground--Continued																					
Handtools:																					
Picks	--	-	--	7	-----	10	10	-	-	-	4	---	52	52	--	-	--	11	-----	25	25
Axes,hatchets, or adzes	--	-	1	15	24	13	13	-	-	-	3	---	7	7	--	-	1	18	24	12	12
Hammers or sledges	--	-	1	20	200	36	44	-	-	-	1	---	3	3	--	-	1	21	200	35	42
Crowbars or bars	--	-	--	31	-----	25	25	-	-	-	3	---	41	41	--	-	--	34	-----	27	27
Shovels	--	-	--	10	-----	20	20	-	-	-	--	---	---	-----	--	-	--	10	-----	20	20
Saws	--	-	1	13	400	9	37	-	-	-	--	---	---	-----	--	-	1	13	400	9	37
Hand wrenches or other tools used to install roof bolts	--	-	--	7	-----	14	14	-	-	-	--	---	---	-----	--	-	--	7	-----	14	14
All tools in hands of fellow workers	--	-	1	13	100	48	52	-	-	-	3	---	21	21	--	-	1	16	100	43	46
Flying particles from handtools or objects worked on	--	-	2	92	1,800	27	65	-	-	-	33	---	4	4	--	-	2	125	1,800	21	49
All other	--	-	1	70	600	20	28	-	-	-	2	---	3	3	--	-	1	72	600	19	27
Stepping or kneeling on sharp or loose objects:																					
Stepping on nails or other sharp objects	--	-	--	13	-----	8	8	-	-	-	17	---	4	4	--	-	--	30	-----	6	6
Stepping on loose objects	--	-	--	94	-----	32	32	-	-	-	7	---	36	36	--	-	--	101	-----	32	32
Knee or hand injuries while working on all fours	--	-	1	61	120	29	30	-	-	-	3	---	14	14	--	-	1	64	120	28	29
Striking or bumping against objects	--	-	1	40	280	17	23	-	-	-	2	---	15	15	--	-	1	42	280	16	23
Haulage:																					
Struck, run over, or squeezed between cars or motors:																					
Coupling or uncoupling	2	-	18	121	342	44	167	-	-	1	6	120	9	25	2	-	19	127	331	43	160
Switching, spragging, blocking, or braking	1	-	5	24	726	33	348	-	-	2	4	250	35	107	1	-	7	28	590	34	308
Pulling, pushing, or dropping	1	-	3	14	205	40	399	-	-	-	1	---	62	62	1	-	3	15	205	42	381
Operating or riding	3	-	3	67	230	25	279	-	-	-	3	---	7	7	3	-	3	70	230	25	269
All other	--	-	6	54	947	51	140	-	-	-	5	---	12	12	--	-	6	59	947	47	130
Squeezed between car or motor and rib, timber, or roof:																					
Coupling or uncoupling	1	-	5	19	1,095	40	489	-	-	-	1	---	2	2	1	-	5	20	1,095	38	471
Switching, spragging, blocking, or braking	--	1	--	9	-----	40	636	-	-	-	1	---	25	25	--	1	--	10	-----	39	581
Pulling, pushing, or dropping	2	-	--	10	-----	53	1,045	-	-	-	1	---	2	2	2	-	--	11	-----	49	964
Operating or riding	5	-	1	149	1,400	37	238	1	-	-	2	---	15	2,010	6	-	1	151	1,400	37	272
All other	--	-	1	19	240	99	106	-	-	-	1	---	152	152	--	-	1	20	240	102	108
Derailments	1	-	--	40	-----	27	173	-	-	-	4	---	18	18	1	-	--	44	-----	27	159
Rerailing cars or motors	1	-	9	68	633	47	191	-	-	-	3	---	53	53	1	-	9	71	633	48	186
Collisions (cars or motors under control)	2	1	1	35	3,600	42	592	-	-	-	--	---	---	-----	2	1	1	35	3,600	42	592
Runaways (cars or motors not under control)	6	-	1	38	30	80	868	-	-	-	1	---	160	160	6	-	1	39	30	82	853
Falling, slipping, or jumping in or from cars or motors	1	-	2	114	970	55	121	-	-	-	8	---	23	23	1	-	2	122	970	53	115
Shuttle cars or mobile electric trucks:																					
Falls of roof or face from shuttle cars or mobile electric trucks knocking out support	1	-	--	4	-----	60	1,248	-	-	-	--	---	---	-----	1	-	--	4	-----	60	1,248
Struck or run over	1	-	--	50	-----	48	165	-	-	-	--	---	---	-----	1	-	--	50	-----	48	165
Squeezed between shuttle car or mobile electric trucks and roof, rib, machine, etc.	5	3	7	241	2,286	53	300	-	-	-	1	---	19	19	5	3	7	242	2,286	53	298
All other	--	-	2	165	950	48	59	-	-	-	1	---	1	1	--	-	2	166	950	47	58
Miscellaneous haulage:																					
Coupling or uncoupling (cars not moving)	--	-	--	18	-----	41	41	-	-	-	2	---	25	25	--	-	--	20	-----	39	39
Ropes or cables on haulage	--	-	5	53	478	62	98	-	-	-	13	---	38	38	--	-	5	66	478	57	87
Slips or strains from pulling, pushing, or dropping car by hand	--	-	--	34	-----	28	28	-	-	-	6	---	13	13	--	-	--	40	-----	26	26
Riding or getting on or off conveyor belts	--	-	--	78	-----	29	29	-	-	-	2	---	3	3	--	-	--	80	-----	25	28
Flying particles on haulage	--	-	--	25	-----	9	9	-	-	-	3	---	3	3	--	-	--	28	-----	8	8
Falls of roof or face from cars or motors knocking out support	1	-	1	6	250	27	802	-	-	-	--	---	---	-----	1	-	1	6	250	27	802
All other	--	-	1	81	200	35	37	-	-	-	3	---	13	13	--	-	1	84	200	34	36
Explosions of gas or coal dust:																					
Open lights	--	-	--	---	-----	--	-----	-	-	-	1	---	14	14	--	-	--	1	-----	14	14
Matches, igniters, or smoking	5	-	--	1	-----	54	5,009	-	-	-	--	---	---	-----	5	-	--	1	-----	54	5,009
Electric arc	10	-	--	6	-----	34	3,763	-	-	-	3	---	27	27	10	-	--	9	-----	31	3,173
Defective flame safety lamp	---	-	--	---	-----	--	-----	-	-	-	1	---	24	24	--	-	--	1	-----	24	24
All other	--	-	--	8	-----	56	56	-	-	-	--	---	---	-----	--	-	--	8	-----	56	56

TABLE 12. - Number and average severity of injuries at coal mines in the United States, by kind of coal, detailed causes of injury, general work location, and degree of injury, 1965--Continued

Causes of injury and general work location	Bituminous-coal mines							Pennsylvania anthracite mines							All coal mines						
	Number of injuries				Average severity			Number of injuries				Average severity			Number of injuries				Average severity		
	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries
UNDERGROUND MINES--Continued																					
Underground--Continued																					
Explosives and breaking agents:																					
Industrial explosives:																					
Premature shot or blast	---	--	---	2	-----	48	48	-	-	-	---	---	---	---	---	--	---	2	-----	48	48
Charging or tamping	---	--	---	1	-----	89	89	-	-	-	1	---	2	2	---	--	---	2	-----	46	46
Misfire or digging into unexploded holes	---	--	---	5	-----	42	42	-	-	-	2	---	2	2	---	--	---	7	-----	31	31
Shot breaking through rib or pillar	---	--	---	13	-----	49	49	-	-	-	---	---	---	---	---	--	---	13	-----	49	49
Blowout or windy shot	---	--	---	2	-----	37	37	-	-	-	---	---	---	---	---	--	---	2	-----	37	37
Flying fragments	1	--	1	26	1,800	30	306	-	-	-	1	---	3	3	1	--	1	27	1,800	29	296
Suffocation from explosives smoke	---	--	---	2	-----	5	5	-	-	-	---	---	---	---	---	--	---	2	-----	5	5
Caps or detonators	---	--	1	---	1,740	---	1,740	-	-	-	1	---	22	22	---	--	1	1	1,740	22	881
Airdox	---	--	---	29	-----	39	39	-	-	-	---	---	---	---	---	--	---	29	-----	39	39
Insufficient warning or improper blasting lines	---	--	---	4	-----	92	92	-	-	-	---	---	---	---	---	--	---	4	-----	92	92
All other	---	--	---	3	-----	12	12	-	-	-	1	---	1	1	---	--	---	4	-----	9	9
Electricity (including sparks or flashes):																					
Trolley wire or pole	1	--	---	21	-----	6	278	-	-	-	1	---	3	3	1	--	---	22	-----	6	266
Transformers, generators, etc.	---	--	---	3	-----	6	6	-	-	-	1	---	6	6	---	--	---	4	-----	6	6
Permanent or semipermanent power or lighting circuits	1	--	---	11	-----	11	510	-	-	-	---	---	---	---	1	--	---	11	-----	11	510
Locomotives or shuttle cars	1	--	---	27	-----	19	232	-	-	-	1	---	2	2	1	--	---	28	-----	18	224
Mining or loading machines	---	--	---	19	-----	14	14	-	-	-	---	---	---	---	---	--	---	19	-----	14	14
Cutout switches or junction boxes	---	--	---	35	-----	13	13	-	-	-	2	---	35	35	---	--	---	37	-----	14	14
Cables on mobile or portable machinery and haulage equipment	---	--	---	164	-----	13	13	-	-	-	1	---	22	22	---	--	---	165	-----	13	13
All other	1	--	---	24	-----	10	250	-	-	-	---	---	---	---	1	--	---	24	-----	10	250
Machinery:																					
While moving mining machines	2	--	2	51	2,288	36	335	-	-	-	---	---	---	---	2	--	2	51	2,288	36	335
While setting up mining machines	1	--	6	75	629	29	146	-	-	-	---	---	---	---	1	--	6	75	629	29	146
While operating mining machines	---	--	11	112	1,314	42	156	-	-	-	---	---	---	---	---	--	11	112	1,314	42	156
Belt conveyors	---	--	11	96	993	36	135	-	-	-	2	---	18	18	---	--	11	98	993	36	132
Chain, bucket, or shaker conveyors	---	--	3	20	433	37	89	-	-	-	10	---	62	62	---	--	3	30	433	45	81
Loading machines (including self-loading heads)	---	--	4	184	135	48	50	-	-	1	7	300	34	67	---	--	5	191	168	48	51
While moving loading machines or self-loading heads	---	--	2	41	250	48	57	-	-	-	1	---	7	7	---	--	2	42	250	47	56
Scraper conveyors	---	--	---	---	-----	---	-----	-	-	1	14	220	15	29	---	--	1	14	220	15	29
Power drills (except for roof bolting)	---	--	4	107	1,738	42	103	-	-	-	15	---	13	13	---	--	4	122	1,738	39	93
Power drills for installing roof bolts	1	--	6	106	213	32	94	-	-	-	---	---	---	---	1	--	6	106	213	32	94
Power equipment (except drills) for installing roof bolts	---	--	9	106	163	25	36	-	-	-	---	---	---	---	---	--	9	106	163	25	36
While moving any machines except mining and loading machines	2	--	2	116	188	38	140	-	-	-	2	---	22	22	2	--	2	118	188	37	138
Flying particles set in motion by machinery (except roof-bolting equipment)	---	--	---	46	-----	8	8	-	-	-	14	---	3	3	---	--	---	60	-----	7	7
Flying particles set in motion by roof bolting equipment	---	--	---	30	-----	7	7	-	-	-	2	---	6	6	---	--	---	32	-----	7	7
While moving, setting up, or operating continuous-mining machines	5	--	8	169	1,085	34	244	-	-	-	---	---	---	---	5	--	8	169	1,085	34	244
Falls of roof or face from machinery knocking out support	3	--	---	5	-----	63	2,290	-	-	-	---	---	---	---	3	--	---	5	-----	63	2,290
All other	---	--	6	49	203	43	61	-	-	-	9	---	17	17	---	--	6	58	203	39	54
Suffocation (no flames or smoldering):																					
From natural mine gases	---	--	---	2	-----	16	16	-	-	-	---	---	---	---	---	--	---	2	-----	16	16
From foreign gases (gasoline fumes, etc.)	---	--	---	2	-----	4	4	-	-	-	---	---	---	---	---	--	---	2	-----	4	4
Mine fires and suffocation from fires:																					
Mine fires: Initiated by electricity	9	--	---	---	-----	---	6,000	-	-	-	---	---	---	---	9	--	---	---	-----	--	6,000
Other fires:																					
Belt conveyors	---	--	---	1	-----	3	3	-	-	-	---	---	---	---	---	--	---	1	-----	3	3
Equipment or material	2	--	---	26	-----	13	441	-	-	-	---	---	---	---	2	--	---	26	-----	13	441
Burning or exploding oil, gasoline, etc.	---	--	---	3	-----	8	8	-	-	-	---	---	---	---	---	--	---	3	-----	8	8

TABLE 12. - Number and average severity of injuries at coal mines in the United States, by kind of coal, detailed causes of injury, general work location, and degree of injury, 1965--Continued

Causes of injury and general work location	Bituminous coal mines							Pennsylvania anthracite mines							All coal mines						
	Number of injuries				Average severity			Number of injuries				Average severity			Number of injuries				Average severity		
	Fatal	Permanent: Total	Permanent: Partial	Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent: Total	Permanent: Partial	Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent: Total	Permanent: Partial	Temporary total	Permanent partial	Temporary total	All injuries
UNDERGROUND MINES--Continued																					
Underground--Continued																					
Miscellaneous causes:																					
Flying particles from draft or wind	---	--	---	-----	---	---	-----	-	-	-	1	---	1	1	---	--	---	1	---	1	1
Acetylene or electric welding (burns, flashes, or flying particles)	---	--	---	28	---	11	11	-	-	-	1	---	1	1	---	--	---	29	---	10	10
Irritations or burns from battery fluid or corrosive materials	---	--	---	26	---	18	18	-	-	-	1	---	17	17	---	--	---	27	---	18	18
Burns from controlled fires	---	--	---	2	---	13	13	-	-	-	---	---	---	---	---	--	---	2	---	13	13
All other	---	--	---	45	---	27	27	-	-	-	---	---	---	---	---	--	---	45	---	27	27
Total or average, underground	208	14	199	7,700	719	39	218	8	-	7	687	199	29	99	216	14	206	8,387	701	38	209
Shaft and slope:																					
Falls of roof:																					
While moving or placing cars in active working places	---	--	---	-----	---	---	-----	-	-	1	---	300	---	300	---	--	1	-----	300	---	300
While setting or pulling timbers or props	---	--	---	1	---	144	144	-	-	-	---	---	---	---	---	--	---	1	---	144	144
All other	---	--	---	1	---	6	6	-	-	-	---	---	---	---	---	--	---	1	---	6	6
Falls of face or rib	---	--	---	1	---	1	1	-	-	-	---	---	---	---	---	--	---	1	---	1	1
Other falling materials or objects: Falling cages	2	--	---	-----	---	---	6,000	-	-	-	---	---	---	---	2	--	---	-----	---	---	6,000
Slips or falls of persons:																					
On same level:																					
While handling materials	---	--	---	2	---	17	17	-	-	-	---	---	---	---	---	--	---	2	---	17	17
While operating or moving machinery	---	--	---	1	---	3	3	-	-	-	---	---	---	---	---	--	---	1	---	3	3
All other	---	--	---	10	---	76	76	-	-	-	---	---	---	---	---	--	---	10	---	76	76
From an elevation:																					
While handling materials	---	--	---	1	---	61	61	-	-	-	---	---	---	---	---	--	---	1	---	61	61
Falls of persons down shaft or slope	1	--	---	3	---	27	1,520	-	-	-	---	---	---	---	1	--	---	3	---	27	1,520
All other	---	--	---	1	---	45	45	-	-	-	---	---	---	---	---	--	---	1	---	45	45
Handling materials:																					
Props, ties, or timbers	---	--	---	2	---	18	18	-	-	-	---	---	---	---	---	--	---	2	---	18	18
Rock or slate	---	--	---	1	---	4	4	-	-	-	---	---	---	---	---	--	---	1	---	4	4
All other	---	--	---	4	---	29	29	-	-	-	---	---	---	---	---	--	---	4	---	29	29
Handtools:																					
Crowbars or bars	---	--	---	1	---	64	64	-	-	-	---	---	---	---	---	--	---	1	---	64	64
All other	---	--	---	2	---	4	4	-	-	-	---	---	---	---	---	--	---	2	---	4	4
Stepping or kneeling on sharp or loose objects:																					
Stepping on nails or other sharp objects	---	--	---	-----	---	---	-----	-	-	-	2	---	3	3	---	--	---	2	---	3	3
Stepping on loose objects	---	--	---	1	---	11	11	-	-	-	1	---	12	12	---	--	---	2	---	12	12
Haulage:																					
Squeezed between car or motor and rib, timber, or roof:																					
Operating or riding	---	--	---	1	---	12	12	-	-	-	---	---	---	---	---	--	---	1	---	12	12
Collisions (cars or motors under control)	---	--	---	1	---	50	50	-	-	-	---	---	---	---	---	--	---	1	---	50	50
Runaways (cars or motors not under control)	---	--	---	-----	---	---	-----	-	-	-	1	---	160	160	---	--	---	1	---	160	160
Falling, slipping, or jumping in or from cars or motors	---	--	---	2	---	10	10	-	-	-	---	---	---	---	---	--	---	2	---	10	10
Miscellaneous haulage: Ropes or cables on haulage	---	--	---	-----	---	---	-----	-	-	-	1	---	30	30	---	--	---	1	---	30	30
Explosions of gas or coal dust: Electric arc	4	--	---	-----	---	---	6,000	-	-	-	---	---	---	---	4	--	---	-----	---	---	6,000
Machinery	---	--	---	1	---	1	1	-	-	-	---	---	---	---	---	--	---	1	---	1	1
Miscellaneous causes: Flying particles from draft or wind	---	--	---	1	---	1	1	-	-	-	---	---	---	---	---	--	---	1	---	1	1
Total or average, shaft and slope	7	--	---	38	---	38	966	-	-	1	5	300	42	85	7	--	1	43	300	39	862

TABLE 12. - Number and average severity of injuries at coal mines in the United States, by kind of coal, detailed causes of injury, general work location, and degree of injury, 1965--Continued

Causes of injury and general work location	Bituminous coal mines							Pennsylvania anthracite mines							All coal mines						
	Number of injuries				Average severity			Number of injuries				Average severity			Number of injuries				Average severity		
	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries
UNDERGROUND MINES--Continued																					
Surface:																					
Falls of coal or overburden:																					
While moving machinery from one working place to another	-	-	-	1	---	39	39	-	-	-	-	---	---	---	-	-	-	1	---	39	39
All other	-	-	-	2	---	25	25	-	-	-	-	---	---	---	-	-	-	2	---	25	25
Other falling materials or objects:																					
Props and timbers	-	-	-	3	---	8	8	-	-	-	-	---	---	---	-	-	-	3	---	8	8
Rolling, shifting, or sliding materials	-	-	-	5	---	84	84	-	-	-	-	---	---	---	-	-	-	5	---	84	84
Falling equipment or machinery under repair	1	-	-	2	---	6	2,004	-	-	-	-	---	---	---	1	-	-	2	---	6	2,004
Rushes, rolls, or slides of coal or rock	-	-	-	2	---	8	8	-	-	-	-	---	---	---	-	-	-	2	---	8	8
All other	-	-	-	5	---	29	29	-	-	-	-	---	---	---	-	-	-	5	---	29	29
Slips or falls of persons:																					
On same level:																					
While handling materials	-	-	-	48	---	29	29	-	-	-	1	---	39	39	-	-	-	49	---	29	29
From handtools slipping or breaking	-	-	-	1	---	7	7	-	-	-	-	---	---	---	-	-	-	1	---	7	7
While operating or moving machinery	-	-	-	7	---	45	45	-	-	-	-	---	---	---	-	-	-	7	---	45	45
All other	-	-	-	31	---	28	28	-	-	-	1	---	15	15	-	-	-	32	---	27	27
From an elevation:																					
While escaping another hazard	-	-	-	1	---	40	40	-	-	-	-	---	---	---	-	-	-	1	---	40	40
While handling materials	-	-	-	24	---	61	61	-	-	-	-	---	---	---	-	-	-	24	---	61	61
While operating or moving machinery	-	-	-	3	---	46	46	-	-	-	1	---	6	6	-	-	-	4	---	36	36
Due to failure of scaffolds, ladders, etc.	-	-	-	6	---	26	26	-	-	-	1	---	11	11	-	-	-	7	---	24	24
All other	1	-	-	12	---	20	480	-	-	-	2	---	17	17	1	-	-	14	---	20	418
Handling materials:																					
Props, ties, or lumber	-	-	-	28	---	39	39	-	-	-	2	---	89	89	-	-	-	30	---	43	43
Coal	-	-	-	21	---	29	29	-	-	-	2	---	18	18	-	-	-	23	---	28	28
Rock or slate	-	-	-	19	---	9	9	-	-	-	2	---	1	1	-	-	-	21	---	8	8
Rails	-	-	-	11	---	39	39	-	-	-	1	---	5	5	-	-	-	12	---	36	36
Wire or wire ropes	-	-	-	7	---	22	22	-	-	-	-	---	---	---	-	-	-	7	---	22	22
Roof-bolting materials	-	-	-	1	---	68	68	-	-	-	-	---	---	---	-	-	-	1	---	68	68
Flying particles from handling materials	-	-	-	18	---	6	6	-	-	-	1	---	2	2	-	-	-	19	---	6	6
All other	-	-	5	211	150	29	32	-	-	-	7	---	28	28	-	-	5	218	150	29	32
Handtools:																					
Picks	-	-	-	1	---	8	8	-	-	-	-	---	---	---	-	-	-	1	---	8	8
Axes, hatchets, or adzes	-	-	1	1	100	5	53	-	-	-	-	----	---	---	-	-	1	1	100	5	53
Hammers or sledges	-	-	-	6	---	22	22	-	-	-	2	---	14	14	-	-	-	8	---	20	20
Crowbars or bars	-	-	-	9	---	30	30	-	-	-	1	---	148	148	-	-	-	10	---	42	42
Shovels	-	-	-	3	---	27	27	-	-	-	-	---	---	---	-	-	-	3	---	27	27
Saws	-	-	-	1	---	2	2	-	-	-	-	---	---	---	-	-	-	1	---	2	2
All tools in hands of fellow workers	-	-	-	3	---	18	18	-	-	-	-	---	---	---	-	-	-	3	---	18	18
Flying particles from handtools or objects worked on	-	-	-	12	---	18	18	-	-	-	-	---	---	---	-	-	-	12	---	18	18
All other	-	-	-	19	---	18	18	-	-	-	1	---	4	4	-	-	-	20	---	17	17
Stepping or kneeling on sharp or loose objects:																					
Stepping on nails or other sharp objects	-	-	-	4	---	4	4	-	-	-	-	---	---	---	-	-	-	4	---	4	4
Stepping on loose objects	-	-	-	21	---	18	18	-	-	-	-	---	---	---	-	-	-	21	---	18	18
Knee or hand injuries while working on all fours	-	-	-	2	---	18	18	-	-	-	-	---	---	---	-	-	-	2	---	18	18
Haulage:																					
Mine-gage haulage:																					
Struck, run over, or squeezed between rail equipment:																					
Coupling or uncoupling	-	-	2	26	250	43	58	-	-	-	1	---	17	17	-	-	2	27	250	42	57
Switching, spragging, blocking, or breaking	-	-	1	---	200	---	200	-	-	-	-	---	---	---	-	-	1	---	200	---	200
Pulling, pushing, or dropping	-	-	1	13	200	12	26	-	-	-	1	---	55	55	-	-	1	14	200	15	28
Operating or riding	-	-	1	5	740	17	138	-	-	-	-	---	---	---	-	-	1	5	740	17	138
All other	-	-	-	10	---	55	55	-	-	-	-	---	---	---	-	-	-	10	---	55	55

TABLE 12. - Number and average severity of injuries at coal mines in the United States, by kind of coal, detailed causes of injury, general work location, and degree of injury, 1965--Continued

Causes of injury and general work location	Bituminous coal mines							Pennsylvania anthracite mines							All coal mines						
	Number of injuries				Average severity			Number of injuries				Average severity			Number of injuries				Average severity		
	Fatal	Permanent		Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent		Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent		Temporary total	Permanent partial	Temporary total	All injuries
		Total	Partial						Total	Partial						Total	Partial				
UNDERGROUND MINES--Continued																					
Surface--Continued																					
Haulage--Continued																					
Mine-gage haulage--Continued																					
Squeezed between rail equipment and construction:																					
Coupling or uncoupling	---	--	---	2	-----	64	64	-	-	-	---	---	---	---	---	--	---	2	-----	64	64
Operating or riding	---	--	---	4	-----	12	12	-	-	-	---	---	---	---	---	--	---	4	-----	12	12
All other	---	--	---	1	-----	90	90	-	-	-	---	---	----	---	---	--	---	1	-----	90	90
Derailments	1	--	---	1	-----	62	3,031	-	-	-	---	---	---	---	1	--	---	1	-----	62	3,031
Rerailing cars or motors	---	--	1	2	200	2	68	-	-	-	---	---	---	---	---	--	1	2	200	2	68
Collisions (cars or motors under control)	---	--	---	2	-----	108	108	-	-	-	---	---	---	---	---	--	---	2	-----	108	108
Runaways (cars or motors not under control)	---	--	---	6	-----	100	100	-	-	-	---	---	---	---	---	--	---	6	-----	100	100
Falling, slipping, or jumping in or from rail equipment	---	--	---	8	-----	57	57	-	-	-	1	---	525	525	---	--	---	9	-----	109	109
Coupling or uncoupling (cars not moving)	---	--	---	1	-----	8	8	-	-	-	---	---	---	---	---	--	---	1	-----	8	8
Ropes or cables on haulage	---	--	---	9	-----	52	52	-	-	-	1	---	8	8	---	--	---	10	-----	48	48
Slips or strains from pushing, pulling, or dropping cars by hand	---	--	---	12	-----	19	19	-	-	-	1	---	25	25	---	--	---	13	-----	19	19
Riding or getting on or off conveyor belts	---	--	---	1	-----	58	58	-	-	-	---	---	---	---	---	--	---	1	-----	58	58
Flying particles on haulage	---	--	---	5	-----	4	4	-	-	-	1	---	1	1	---	--	---	6	-----	4	4
All other	---	--	---	12	-----	30	30	-	-	-	---	---	---	---	---	--	---	12	-----	30	30
Shuttle cars or mobile electric trucks:																					
Struck or run over	---	--	---	2	-----	11	11	-	-	-	---	---	---	---	---	--	---	2	-----	11	11
Squeezed between shuttle car or mobile electric trucks and roof, rib, machine, etc.	---	--	---	6	-----	9	9	-	-	-	---	---	---	---	---	--	---	6	-----	9	9
All other	---	--	---	6	-----	48	48	-	-	-	---	---	---	---	---	--	---	6	-----	48	48
Standard-gage haulage (railway)	4	1	1	101	60	46	324	-	-	-	1	---	3	3	4	1	1	102	60	45	321
Trucks, tractors, automobiles, etc.	2	--	1	41	400	37	316	-	-	-	3	---	32	32	2	--	1	44	400	36	298
Water transportation	---	--	---	2	-----	67	67	-	-	-	---	---	---	---	---	--	---	2	-----	67	67
Explosions of gas or coal dust	---	--	---	5	-----	56	56	-	-	-	---	---	---	---	---	--	---	5	-----	56	56
Explosives and breaking agents: Caps or detonators	---	--	---	1	-----	48	48	-	-	-	---	---	---	---	---	--	---	1	-----	48	48
Electricity (including sparks or flashes):																					
Trolley wire or pole	---	--	---	1	-----	7	7	-	-	-	---	---	---	---	---	--	---	1	-----	7	7
Transformers, generators, etc.	---	--	---	2	-----	73	73	-	-	-	1	---	6	6	---	--	---	3	-----	51	51
Permanent or semipermanent power or lighting circuits	2	--	---	2	-----	53	3,027	-	-	-	---	---	---	---	2	--	---	2	-----	53	3,027
Cutout switches or junction boxes	---	--	---	8	-----	14	14	-	-	-	---	---	---	---	---	--	---	8	-----	14	14
Cables on mobile or portable machinery and haulage equipment	---	--	---	7	-----	3	3	-	-	-	---	---	---	---	---	--	---	7	-----	3	3
All other	---	--	---	2	-----	14	14	-	-	-	---	---	---	---	---	--	---	2	-----	14	14
Machinery:																					
Belt conveyors	1	--	3	19	3,067	18	676	-	-	-	---	---	---	---	1	--	3	19	3,067	18	676
Chain, bucket, or shaker conveyors	---	--	2	1	3,450	82	2,327	-	-	-	---	---	---	---	---	--	2	1	3,450	82	2,327
Power drills	---	--	1	---	200	---	200	-	-	-	---	---	---	---	---	--	1	-----	200	---	200
Power shovels, draglines, bulldozers, etc.	---	--	2	15	150	37	51	-	-	-	2	---	16	16	---	--	2	17	150	35	47
Stationary surface machinery	1	--	---	7	-----	97	835	-	-	-	1	---	1	1	1	--	---	8	-----	85	742
While moving any machine except mining and loading machines	3	--	---	15	-----	20	1,017	-	-	-	2	---	22	22	3	--	---	17	-----	20	917
Flying particles set in motion by machinery	---	--	---	8	-----	24	24	-	-	-	1	---	1	1	---	--	---	9	-----	21	21
Machines on surface for repair, etc.	---	--	---	3	-----	35	35	-	-	-	---	---	---	---	---	--	---	3	-----	35	35
All other	---	--	2	10	645	106	196	-	-	-	1	---	4	4	---	--	2	11	645	97	181
Mine fires and suffocation from fires:																					
Equipment or material	---	--	---	2	-----	13	13	-	-	-	---	---	---	---	---	--	---	2	-----	13	13
Burning or exploding oil, gasoline, etc.	---	--	---	6	-----	13	13	-	-	-	---	---	---	---	---	--	---	6	-----	13	13
Miscellaneous causes:																					
Flying particles from draft or wind	---	--	---	2	-----	1	1	-	-	-	---	---	---	---	---	--	---	2	-----	1	1
Acetylene or electric welding (burns, flashes, or flying particles)	---	--	---	21	-----	20	20	-	-	-	---	---	---	---	---	--	---	21	-----	20	20
Irritations or burns from battery fluid or corrosive materials	---	--	---	9	-----	16	16	-	-	-	1	---	17	17	---	--	---	10	-----	16	16
Burns from controlled fires	1	--	---	1	-----	28	3,014	-	-	-	1	---	16	16	1	--	---	2	-----	22	2,015
All other	---	--	1	7	2,000	25	272	-	-	-	---	---	---	---	---	--	1	7	2,000	25	272
Total or average, surface	17	1	25	983	922	32	159	-	-	-	45	---	35	35	17	1	25	1,028	922	32	154
Total or average, underground mines	232	15	224	8,721	741	38	215	8	-	8	737	211	29	95	240	15	232	9,458	723	37	206

TABLE 12. - Number and average severity of injuries at coal mines in the United States, by kind of coal, detailed causes of injury, general work location, and degree of injury, 1965--Continued

Causes of injury and general work location	Bituminous coal mines: Number of injuries: Fatal	Permanent: Total	Permanent: Partial	Temporary total	Average severity: Permanent partial	Temporary total	All injuries	Pennsylvania anthracite mines: Number of injuries: Fatal	Permanent: Total	Permanent: Partial	Temporary total	Average severity: Permanent partial	Temporary total	All injuries	All coal mines: Number of injuries: Fatal	Permanent: Total	Permanent: Partial	Temporary total	Average severity: Permanent partial	Temporary total	All injuries
STRIP MINES																					
Falls of coal or overburden:																					
While mining	---	--	1	10	600	99	144	-	-	-	1	---	16	16	---	--	1	11	600	91	134
While loading	1	--	---	4	-----	70	1,256	-	-	-	---	---	---	---	1	--	---	4	-----	70	1,256
While moving machinery from one working place to another	---	--	---	1	-----	17	17	-	-	-	---	---	---	---	---	--	---	1	-----	17	17
All other	1	--	---	9	-----	30	627	-	-	-	---	---	---	---	1	--	---	9	-----	30	627
Other falling materials or objects:																					
Rolling, shifting, or sliding materials	---	--	---	7	-----	48	48	-	-	-	2	---	98	98	---	--	---	9	-----	59	59
Falling equipment or machinery under repair	---	--	1	1	300	1	151	-	-	-	2	---	6	6	---	--	1	3	300	4	78
Rushes, rolls, or slides of coal or rock	1	--	---	6	-----	81	926	-	-	-	3	---	8	8	1	--	---	9	-----	57	651
Slips or falls of persons:																					
On same level:																					
While escaping another hazard	---	--	---	1	-----	89	89	-	-	-	---	---	---	---	---	--	---	1	-----	89	89
While handling materials	---	--	---	46	-----	18	18	-	-	-	10	---	38	38	---	--	---	56	-----	22	22
From handtools slipping or breaking	---	--	---	6	-----	13	13	-	-	-	---	---	---	---	---	--	---	6	-----	13	13
While operating or moving machinery	---	--	---	19	-----	16	16	-	-	-	7	---	6	6	---	--	---	26	-----	14	14
All other	---	--	---	27	-----	38	38	-	-	-	3	---	6	6	---	--	---	30	-----	35	35
From an elevation:																					
While escaping another hazard	1	--	---	1	-----	6	3,003	-	-	-	---	---	---	---	1	--	---	1	-----	6	3,003
While handling materials	1	--	---	20	-----	10	295	-	-	-	2	---	8	8	1	--	---	22	-----	10	270
From handtools slipping or breaking	---	--	---	-----	-----	---	-----	-	-	-	4	---	9	9	---	--	---	4	-----	9	9
While operating or moving machinery	---	--	1	30	700	37	59	-	-	-	5	---	8	8	---	--	1	35	700	33	52
Due to failure of scaffolds, ladders, etc.	---	--	---	7	-----	65	65	-	-	-	1	---	11	11	---	--	---	8	-----	58	58
All other	---	--	---	17	-----	14	14	-	-	-	---	---	---	---	---	--	---	17	-----	14	14
Handling materials:																					
Props, ties, or lumber	---	--	1	10	50	25	27	-	-	-	1	---	36	36	---	--	1	11	50	26	28
Coal	---	--	---	16	-----	30	30	-	-	-	1	---	15	15	---	--	---	17	-----	29	29
Rock or slate	---	--	---	10	-----	14	14	-	-	-	3	---	1	1	---	--	---	13	-----	11	11
Rails	---	--	---	5	-----	17	17	-	-	-	---	---	---	---	---	--	---	5	-----	17	17
Wire or wire ropes	---	--	---	25	-----	19	19	-	-	-	1	---	13	13	---	--	---	26	-----	19	19
Handling, moving, or installing conveyor pans	---	--	---	1	-----	1	1	-	-	-	1	---	13	13	---	--	---	2	-----	7	7
Flying particles from handling materials	---	--	---	11	-----	7	7	-	-	-	---	---	---	---	---	--	---	11	-----	7	7
All other	---	--	3	213	175	22	24	-	-	-	22	---	7	7	---	--	3	235	175	21	23
Handtools:																					
Hammers or sledges	---	--	---	9	-----	13	13	-	-	-	---	---	---	---	---	--	---	9	-----	13	13
Crowbars or bars	---	--	---	14	-----	24	24	-	-	-	3	---	10	10	---	--	---	17	-----	22	22
All tools in hands of fellow workers	---	--	---	2	-----	8	8	-	-	-	---	---	---	---	---	--	---	2	-----	8	8
Flying particles from handtools or objects worked on	---	--	1	17	1,800	16	115	-	-	-	4	---	11	11	---	--	1	21	1,800	15	96
All other	---	--	---	18	-----	6	6	-	-	-	1	---	16	16	---	--	---	19	-----	6	6
Stepping or kneeling on sharp or loose objects	---	--	---	24	-----	17	17	-	-	-	2	---	4	4	---	--	---	26	-----	16	16
Striking or bumping against objects	---	--	---	1	-----	25	25	-	-	-	---	---	---	---	---	--	---	1	-----	25	25
Haulage:																					
Mine-gage haulage	---	--	---	20	-----	10	10	-	-	-	4	---	12	12	---	--	---	24	-----	11	11
Standard-gage haulage	---	--	2	128	150	27	29	-	-	-	21	---	63	63	---	--	2	149	150	32	34
Shuttle cars and mobile electric trucks	---	--	---	2	-----	147	147	-	-	-	---	---	---	---	---	--	---	2	-----	147	147
Water transportation	---	--	---	2	-----	13	13	-	-	-	---	---	---	---	---	--	---	2	-----	13	13
Explosives and breaking agents	1	--	---	10	-----	46	588	-	-	-	3	---	2	2	1	--	---	13	-----	36	462
Electricity	3	--	---	8	-----	44	1,668	-	-	-	---	---	---	---	3	--	---	8	-----	44	1,668
Machinery:																					
Belt conveyors	---	--	3	10	2,525	10	591	-	-	-	---	---	---	---	---	--	3	10	2,525	10	591
Chain, bucket, or shaker conveyors	---	--	1	3	100	27	45	-	-	-	---	---	---	---	---	--	1	3	100	27	45
Power drills	---	--	3	18	305	45	82	-	-	-	3	---	47	47	---	--	3	21	305	45	78
Power shovels, draglines, bulldozers, etc.	6	--	9	101	1,044	31	419	-	-	-	19	---	15	15	6	--	9	120	1,044	29	362
Stationary surface machinery	---	--	---	5	-----	28	28	-	-	-	1	---	22	22	---	--	---	6	-----	27	27
While moving any machine except mining and loading machines	2	--	---	14	-----	7	756	-	-	-	2	---	104	104	2	--	---	16	-----	19	684
Flying particles set in motion by machinery	---	--	---	8	-----	7	7	-	-	-	3	---	3	3	---	--	---	11	-----	6	6
All other	---	--	1	14	200	48	58	-	-	-	---	---	---	---	---	--	1	14	200	48	58
Mine fires and suffocation from fires:																					
Equipment or material	---	--	---	2	------	6	6	-	-	-	---	---	---	---	---	--	---	2	-----	6	6
Burning or exploding oil, gasoline, etc.	---	--	---	5	-----	44	44	-	-	-	---	---	---	---	---	--	---	5	-----	44	44

TABLE 12. - Number and average severity of injuries at coal mines in the United States, by kind of coal, detailed causes of injury, general work location, and degree of injury, 1965--Continued

Causes of injury and general work location	Bituminous coal mines							Pennsylvania anthracite mines							All coal mines						
	Number of injuries				Average severity			Number of injuries				Average severity			Number of injuries				Average severity		
	Fatal	Permanent		Tempo-rary total	Perma-nent partial	Tempo-rary total	All in-juries	Fatal	Permanent		Tempo-rary total	Perma-nent partial	Tempo-rary total	All in-juries	Fatal	Permanent		Tempo-rary total	Perma-nent partial	Tempo-rary total	All in-juries
		Total	Partial						Total	Partial						Total	Partial				
STRIP MINES--Continued																					
Miscellaneous causes:																					
Flying particles from draft or wind	---	--	---	6	-----	6	6	-	-	--	-----	---	--	--	---	--	---	6	-----	6	6
Acetylene or electric welding (burns, flashes, or flying particles)	---	--	---	30	-----	7	7	-	-	--	4	---	23	23	---	--	---	34	-----	9	9
Irritations or burns from battery fluid or corrosive materials	---	--	---	9	-----	7	7	-	-	--	2	---	13	13	---	--	---	11	-----	8	8
Burns from controlled fires	---	--	---	8	-----	13	13	-	-	--	4	---	58	58	---	--	---	12	-----	28	28
All other	1	1	---	13	-----	18	816	-	-	--	1	---	1	1	1	1	---	14	-----	17	765
Total or average, strip mines	18	1	27	1,004	832	25	154	-	-	--	146	---	24	24	18	1	27	1,150	832	25	138
AUGER MINES																					
Falls of coal or overburden	1	--	---	1	-----	5	3,003	-	-	--	-----	---	--	--	1	--	---	1	-----	5	3,003
Other falling materials or objects	---	--	---	1	-----	48	48	-	-	--	-----	---	--	--	---	--	---	1	-----	48	48
Slips or falls of persons:																					
On same level	---	--	---	3	-----	25	25	-	-	--	-----	---	--	--	---	--	---	3	-----	25	25
From an elevation	---	--	---	3	-----	25	25	-	-	--	-----	---	--	--	---	--	---	3	-----	25	25
Handling materials	---	--	---	25	-----	37	37	-	-	--	-----	---	--	--	---	--	---	25	-----	37	37
Handtools	---	--	---	4	-----	14	14	-	-	--	-----	---	--	--	---	--	---	4	-----	14	14
Stepping on loose (not sharp) objects	---	--	---	1	-----	31	31	-	-	--	-----	---	--	--	---	--	---	1	-----	31	31
Haulage:																					
Mine-gage haulage	---	--	---	2	-----	22	22	-	-	--	-----	---	--	--	---	--	---	2	-----	22	22
Standard-gage haulage	---	--	---	2	-----	29	29	-	-	--	-----	---	--	--	---	--	---	2	-----	29	29
Machinery	---	--	1	32	1,140	40	73	-	-	--	-----	---	--	--	---	--	1	32	1,140	40	73
Miscellaneous causes	---	--	---	4	-----	3	3	-	-	--	-----	---	--	--	---	--	---	4	-----	3	3
Total or average, auger mines	1	--	1	78	1,140	33	122	-	-	--	-----	---	--	--	1	--	1	78	1,140	33	122
CULM BANKS																					
Slips or falls of persons	---	--	---	-----	-----	--	-----	-	-	-	1	---	45	45	---	--	---	1	-----	45	45
Handling materials	---	--	---	-----	-----	--	-----	-	-	-	2	---	32	32	---	--	---	2	-----	32	32
Handtools	---	--	---	-----	-----	--	-----	-	-	-	1	---	1	1	---	--	---	1	-----	1	1
Haulage	---	--	---	-----	-----	--	-----	-	-	-	3	---	19	19	---	--	---	3	-----	19	19
Machinery	---	--	---	-----	-----	--	-----	-	-	-	5	---	32	32	---	--	---	5	-----	32	32
All other causes	---	--	---	-----	-----	--	-----	-	-	-	1	---	6	6	---	--	---	1	-----	6	6
Total or average, culm banks	---	--	---	-----	-----	--	-----	-	-	-	13	---	25	25	---	--	---	13	-----	25	25
DREDGES																					
All causes	---	--	---	-----	-----	--	-----	-	-	-	1	---	28	28	---	--	---	1	-----	28	28
PREPARATION PLANTS																					
Other falling materials or objects	---	--	---	-----	-----	--	-----	-	-	-	4	---	9	9	---	--	---	4	-----	9	9
Slips or falls of persons:																					
On same level:																					
While handling materials	---	--	---	-----	-----	--	-----	-	-	-	8	---	24	24	---	--	---	8	-----	24	24
While operating or moving machinery	---	--	---	-----	-----	--	-----	-	-	-	7	---	19	19	---	--	---	7	-----	19	19
All other	---	--	---	-----	-----	--	-----	-	-	-	4	---	39	39	---	--	---	4	-----	39	39
From an elevation:																					
While handling materials	----	--	---	-----	-----	--	-----	-	-	-	9	---	66	66	---	--	---	9	-----	66	66
While operating or moving machinery	---	--	---	-----	-----	--	-----	-	-	-	1	----	6	6	---	--	---	1	-----	6	6
All other	---	--	---	-----	-----	--	-----	-	-	-	4	---	73	73	---	--	---	4	-----	73	73
Handling materials:																					
Props, ties, or lumber	---	--	---	-----	-----	--	-----	-	-	-	4	---	24	24	---	--	---	4	-----	24	24
Coal	---	--	---	-----	-----	--	-----	-	-	-	1	---	6	6	---	--	---	1	-----	6	6
Rock or slate	---	--	---	-----	-----	--	-----	-	-	1	6	100	68	72	---	--	1	6	100	68	72
Wire or wire ropes	---	--	---	-----	-----	--	-----	-	-	-	2	---	13	13	---	--	---	2	-----	13	13
Flying particles while loading car of coal, rock, or gob	---	--	---	-----	-----	--	-----	-	-	-	1	---	1	1	---	--	---	1	-----	1	1
Flying particles from handling materials	---	--	---	-----	-----	--	-----	-	-	-	2	---	4	4	---	--	---	2	-----	4	4
All other	---	--	---	-----	-----	--	-----	-	-	-	23	---	35	35	---	--	---	23	-----	35	35

TABLE 12. - Number and average severity of injuries at coal mines in the United States, by kind of coal, detailed causes of injury, general work location, and degree of injury, 1965--Continued

Causes of injury and general work location	Bituminous coal mines							Pennsylvania anthracite mines							All coal mines						
	Number of injuries				Average severity			Number of injuries				Average severity			Number of injuries				Average severity		
	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries
PREPARATION PLANTS--Continued																					
Handtools	---	--	---	-----	---	--	---	-	-	--	13	---	24	24	---	--	---	13	---	24	24
Stepping on sharp or loose objects	---	--	---	-----	---	--	---	-	-	--	1	---	3	3	---	--	---	1	---	3	3
Striking or bumping against objects	---	--	---	-----	---	--	---	-	-	--	1	---	6	6	---	--	---	1	---	6	6
Haulage:																					
Mine-gage haulage	---	--	---	-----	---	--	---	-	-	--	2	---	30	30	---	--	---	2	---	30	30
Standard-gage haulage (railway)	---	--	---	-----	---	--	---	-	-	1	36	50	32	32	---	--	1	36	50	32	32
Electricity	---	--	---	-----	---	--	---	-	-	--	2	---	34	34	---	--	---	2	---	34	34
Machinery:																					
Chain, bucket, or shaker conveyors	---	--	---	-----	---	--	---	-	-	1	10	470	21	61	---	--	1	10	470	21	61
Power drills	----	--	---	-----	---	--	---	-	-	--	1	---	99	99	---	--	---	1	---	99	99
Power shovels, draglines, bulldozers, etc.	---	--	---	-----	---	--	---	-	-	--	2	---	71	71	---	--	---	2	---	71	71
Stationary surface machinery	---	--	---	-----	---	--	---	-	-	--	2	---	5	5	---	--	---	2	---	5	5
Flying particles set in motion by machinery	---	--	---	-----	---	--	---	-	-	--	1	---	18	18	---	--	---	1	---	18	18
All other	---	--	---	-----	---	--	---	-	-	--	2	---	47	47	---	--	---	2	---	47	47
Suffocation (no flames or smoldering): From foreign gases (gasoline fumes, etc.)	---	--	---	-----	---	--	---	-	-	--	1	---	13	13	---	--	---	1	---	13	13
Miscellaneous causes:																					
Flying particles from draft or wind	---	--	---	-----	---	--	---	-	-	--	1	---	2	2	----	--	---	1	---	2	2
Acetylene or electric welding (burns, flashes, or flying particles)	---	--	---	-----	---	--	---	-	-	--	4	---	3	3	---	--	---	4	---	3	3
Burns from controlled fires	---	--	---	-----	---	--	---	-	-	--	2	---	46	46	---	--	---	2	---	46	46
All other	---	--	---	-----	---	--	---	-	-	--	2	---	7	7	---	--	---	2	---	7	7
Total or average, preparation plants	---	--	---	-----	---	--	---	-	-	3	159	207	32	35	---	--	3	159	207	32	35
Grand total	251	16	252	9,803	752	37	208	8	-	11	1,056	210	29	75	259	16	263	10,859	730	36	196

TABLE 13. - Number of injuries, average severity, and injury rates at bituminous-coal mines in the United States, by part of body injured, 1965

General work location and part of body injured	Number of injuries						Distribution of all injuries, percent	Average severity			Severity rates per million man-hours		Frequency rates per million man-hours	
	Fatal	Nonfatal				All injuries		Permanent partial	Temporary total	All injuries	Fatal	Nonfatal	Fatal	Nonfatal
		Permanent		Temporary total	Total nonfatal									
		Total	Partial											
Underground mines:														
Underground (including shaft and slope):														
Head	41	1	2	459	462	503	6.9	330	25	525	1,608	118	0.27	3.02
Eye	---	--	5	371	376	376	5.2	1,800	13	36	-----	89	----	2.46
Trunk	58	11	8	2,235	2,254	2,312	31.7	808	40	221	2,274	1,060	.38	14.73
Hernia	---	--	1	89	90	90	1.2	50	62	62	-----	36	----	.59
Arm	---	--	8	285	293	293	4.0	3,653	46	144	-----	276	----	1.91
Hand and finger, including wrist	---	--	149	1,247	1,396	1,396	19.2	325	26	58	-----	529	----	9.12
Leg	2	--	10	945	955	957	13.1	3,192	56	101	78	553	.01	6.24
Foot and toe, including ankle	---	--	15	817	832	832	11.4	845	40	55	-----	297	----	5.44
Multiple	114	2	1	411	414	528	7.2	4,500	49	1,365	4,470	238	.74	2.71
Not stated	---	--	---	879	879	879	----	-----	42	42	-----	240	----	5.74
Total or average	215	14	199	7,738	7,951	8,166	----	719	39	222	8,430	3,437	1.41	51.96
Surface:														
Head	2	--	---	46	46	48	5.0	-----	25	274	336	32	.06	1.29
Eye	---	--	---	64	64	64	6.7	-----	9	9	-----	16	----	1.79
Trunk	2	--	1	315	316	318	33.0	2,000	30	74	336	319	.06	8.84
Hernia	---	--	---	26	26	26	2.7	-----	51	51	-----	37	----	.73
Arm	---	--	3	28	31	31	3.2	4,500	62	491	-----	426	----	.87
Hand and finger, including wrist	---	--	18	129	147	147	15.3	261	23	52	-----	215	----	4.11
Leg	1	1	---	112	113	114	11.9	-----	58	162	168	348	.03	3.16
Foot and toe, including ankle	---	--	3	136	139	139	14.5	950	33	53	-----	206	----	3.89
Multiple	12	--	---	62	62	74	7.7	-----	31	999	2,015	54	.34	1.74
Not stated	---	--	---	65	65	65	----	-----	27	27	-----	49	----	1.82
Total or average	17	1	25	983	1,009	1,026	----	922	32	159	2,855	1,704	.48	28.24
Total or average, underground mines	232	15	224	8,721	8,960	9,192	----	741	38	215	7,375	3,109	1.23	47.47
Strip mines:														
Head	6	--	---	67	67	73	7.7	-----	20	511	868	32	.14	1.62
Eye	---	--	1	73	74	74	7.8	1,800	8	32	-----	57	----	1.78
Trunk	1	1	2	315	318	319	33.5	650	27	68	145	381	.02	7.67
Hernia	---	--	1	21	22	22	2.3	50	52	52	-----	28	----	.53
Arm	---	--	2	43	45	45	4.7	4,050	23	202	-----	219	----	1.08
Hand and finger, including wrist	---	--	19	130	149	149	15.7	416	25	75	-----	270	----	3.59
Leg	---	--	1	112	113	113	11.9	3,000	29	56	-----	151	----	2.72
Foot and toe, including ankle	1	--	1	108	109	110	11.6	300	23	80	145	67	.02	2.63
Multiple	10	--	---	37	37	47	4.9	-----	17	1,290	1,446	15	.24	.89
Not stated	---	--	---	98	98	98	-----	-----	30	30	-----	70	----	2.36
Total or average	18	1	27	1,004	1,032	1,050	-----	832	25	154	2,604	1,291	.43	24.88

TABLE 13. - Number of injuries, average severity, and injury rates at bituminous-coal mines in the United States, by part of body injured, 1965--Continued

General work location and part of body injured	Number of injuries						Distribution of all injuries, percent	Average severity			Severity rates per million man-hours		Frequency rates per million man-hours	
	Fatal	Nonfatal				All injuries		Permanent partial	Temporary total	All injuries	Fatal	Nonfatal	Fatal	Nonfatal
		Permanent		Temporary total	Total nonfatal									
		Total	Partial											
Auger mines:														
Head	---	--	---	1	1	1	2.0	-----	1	1	-----	(1/)	----	.42
Eye	---	--	---	3	3	3	5.9	-----	1	1	-----	1	----	1.26
Trunk	---	--	---	19	19	19	37.2	-----	58	58	-----	461	----	7.98
Arm	---	--	---	2	2	2	3.9	-----	27	27	-----	22	----	.84
Hand and finger, including wrist	---	--	1	10	11	11	21.6	1,140	27	128	-----	591	----	4.62
Leg	---	--	---	8	8	8	15.7	-----	19	19	-----	63	----	3.36
Foot and toe, including ankle	---	--	---	3	3	3	5.9	-----	8	8	-----	11	----	1.26
Multiple	1	--	---	3	3	4	7.8	-----	18	1,513	2,521	22	.42	1.26
Not stated	---	--	---	29	29	29	-----	-----	32	32	-----	396	----	12.19
Total or average	1	--	1	78	79	80	-----	1,140	33	122	2,521	1,568	.42	33.20
Grand total or average	251	16	252	9,803	10,071	10,322	-----	752	37	208	6,474	2,769	1.08	43.30

1/ Less than 0.5

TABLE 14. - Number of injuries, average severity, and injury rates at Pennsylvania anthracite mines, by part of body injured, 1965

General work location and part of body injured	Number of injuries						Distribution of all injuries, percent	Average severity			Severity rates per million man-hours		Frequency rates per million man-hours	
	Fatal	Nonfatal				All injuries		Permanent partial	Temporary total	All injuries	Fatal	Nonfatal	Fatal	Nonfatal
		Permanent		Temporary total	Total nonfatal									
		Total	Partial											
Underground mines:														
Underground (including shaft and slope):														
Head	2	-	--	75	75	77	11.1	---	19	175	1,862	226	0.31	11.64
Eye	-	-	--	67	67	67	9.7	---	5	5	-----	49	----	10.40
Trunk	5	-	--	164	164	169	24.5	---	31	208	4,655	800	.78	25.45
Hernia	-	-	--	4	4	4	.6	---	42	42	-----	26	----	.62
Arm	-	-	--	25	25	25	3.6	---	36	36	-----	138	----	3.88
Hand and finger, including wrist	-	-	6	125	131	131	19.0	195	28	35	-----	715	----	20.33
Leg	-	-	--	100	100	100	14.5	---	49	49	-----	762	----	15.52
Foot and toe, including ankle	-	-	2	97	99	99	14.3	260	31	36	-----	552	----	15.36
Multiple	1	-	--	18	18	19	2.7	---	19	334	931	53	.16	2.79
Not stated	-	-	--	17	17	17	-----	---	20	20	-----	52	----	2.64
Total or average	8	-	8	692	700	708	-----	211	29	98	7,449	3,373	1.24	108.63

TABLE 14. - Number of injuries, average severity, and injury rates at Pennsylvania anthracite mines, by part of body injured, 1965--Continued

General work location and part of body injured	Number of injuries						Distribution of all injuries, percent	Average severity			Severity rates per million man-hours		Frequency rates per million man-hours	
	Fatal	Nonfatal				All injuries		Permanent partial	Temporary total	All injuries	Fatal	Nonfatal	Fatal	Nonfatal
		Permanent		Temporary total	Total nonfatal									
		Total	Partial											
Underground mines--Continued														
Surface (including culm banks, dredges, and preparation plants):														
Head	-	-	--	8	8	8	3.6	---	11	11	-----	14	---	1.27
Eye	-	-	--	19	19	19	8.6	---	4	4	-----	12	---	3.01
Trunk	-	-	--	68	68	68	30.8	---	27	27	-----	286	---	10.78
Hernia	-	-	--	6	6	6	2.7	---	74	74	-----	70	---	.95
Arm	-	-	--	4	4	4	1.8	---	38	38	-----	24	---	.63
Hand and finger, including wrist	-	-	3	43	46	46	20.8	207	29	41	-----	298	---	7.29
Leg	-	-	--	31	31	31	14.0	---	48	48	-----	238	---	4.92
Foot and toe, including ankle	-	-	--	27	27	27	12.2	---	51	51	-----	220	---	4.28
Multiple	-	-	--	12	12	12	5.4	---	19	19	-----	37	---	1.90
Not stated	-	-	--	-----	-----	-----	----	---	--	---	-----	-----	---	------
Total or average	-	-	3	218	221	221	----	207	32	34	-----	1,200	---	35.04
Total or average, underground mines	8	-	11	910	921	929	----	210	30	83	3,765	2,298	.63	72.23
Strip mines:														
Head	-	-	--	12	12	12	9.7	---	22	22	-----	73	---	3.31
Eye	-	-	--	5	5	5	4.0	---	3	3	-----	4	---	1.38
Trunk	-	-	--	36	36	36	29.0	---	19	19	-----	190	---	9.93
Hernia	-	-	--	3	3	3	2.4	---	52	52	-----	43	---	.83
Arm	-	-	--	5	5	5	4.0	---	16	16	-----	22	---	1.38
Hand and finger, including wrist	-	-	--	13	13	13	10.5	---	20	20	-----	71	---	3.59
Leg	-	-	--	26	26	26	21.0	---	28	28	-----	200	---	7.17
Foot and toe, including ankle	-	-	--	11	11	11	8.9	---	37	37	-----	114	---	3.03
Multiple	-	-	--	13	13	13	10.5	---	35	35	-----	127	---	3.59
Not stated	-	-	--	22	22	22	----	---	21	21	-----	127	---	6.07
Total or average	-	-	--	146	146	146	----	---	24	24	-----	971	---	40.28
Grand total or average	8	-	11	1,056	1,067	1,075	----	210	29	75	2,931	2,004	.49	65.16

TABLE 15. - Number of injuries and average severity by degree at coal mines in the United States, by part of body and major cause of injury, 1965

Major causes of injury	Bituminous-coal mines: Number of injuries: Fatal	Permanent: Total	Permanent: Partial	Temporary total	Average severity: Permanent partial	Temporary total	All injuries	Pennsylvania anthracite mines: Number of injuries: Fatal	Permanent: Total	Permanent: Partial	Temporary total	Average severity: Permanent partial	Temporary total	All injuries	All coal mines: Number of injuries: Fatal	Permanent: Total	Permanent: Partial	Temporary total	Average severity: Permanent partial	Temporary total	All injuries
Head:																					
Falls of roof	26	1	2	81	330	32	1,502	-	-	--	4	---	188	188	26	1	2	85	330	39	1,456
Falls of face or rib	1	--	---	20	-----	41	325	-	-	--	8	---	19	19	1	--	---	28	-----	35	241
Pressure bumps or bursts	1	--	---	3	-----	10	1,508	-	-	--	1	---	2	2	1	--	---	4	-----	8	1,207
Inrush of water and material	---	--	---	-----	-----	---	-----	2	-	--	-----	---	---	6,000	2	--	---	------	-----	---	6,000
Other falling objects	1	--	---	10	-----	11	556	-	-	--	7	---	9	9	1	--	---	17	-----	10	343
Falls of persons	---	--	---	16	-----	40	40	-	-	--	12	---	11	11	---	--	---	28	-----	27	27
Handling materials	---	--	---	65	-----	12	12	-	-	--	20	---	10	10	---	--	---	85	-----	11	11
Handtools	---	--	---	39	-----	14	14	-	-	--	8	---	4	4	---	--	---	47	-----	12	12
Striking or bumping	---	--	---	12	-----	10	10	-	-	--	1	---	15	15	---	--	---	13	-----	10	10
Haulage	10	--	---	144	-----	27	415	-	-	--	11	---	24	24	10	--	---	155	-----	27	389
Explosions (gas or dust)	---	--	---	9	-----	47	47	-	-	--	3	---	26	26	---	--	---	12	-----	42	42
Explosives	1	--	---	28	-----	41	246	-	-	--	4	---	2	2	1	--	---	32	-----	36	217
Electricity	---	--	---	33	-----	11	11	-	-	--	-----	---	---	-----	---	--	---	33	-----	11	11
Machinery	8	--	---	94	-----	24	493	-	-	--	15	---	6	6	8	--	---	109	-----	21	430
Mine fires	---	--	---	3	-----	8	8	-	-	--	-----	---	---	-----	---	--	---	3	-----	8	8
All other	1	--	---	16	-----	10	362	-	-	--	1	---	9	9	1	--	---	17	-----	9	342
Total or average	49	1	2	573	330	24	503	2	-	--	95	---	19	142	51	1	2	668	330	23	455
Eye:																					
Falls of roof	---	--	---	16	-----	6	6	-	-	--	2	---	15	15	---	--	---	18	-----	7	7
Falls of face or rib	---	--	---	3	-----	2	2	-	-	--	1	---	1	1	---	--	---	4	-----	2	2
Pressure bumps or bursts	---	--	---	-----	-----	---	-----	-	-	--	3	---	9	9	---	--	---	3	-----	9	9
Other falling objects	---	--	---	7	-----	6	6	-	-	--	-----	---	---	-----	---	--	---	7	-----	6	6
Falls of persons	---	--	---	1	-----	25	25	-	-	--	1	---	9	9	---	--	---	2	-----	17	17
Handling materials	---	--	---	91	-----	10	10	-	-	--	17	---	5	5	---	--	---	108	-----	9	9
Handtools	---	--	3	86	1,800	29	88	-	-	--	30	---	4	4	---	--	3	116	1,800	22	67
Stepping on objects	---	--	---	-----	-----	---	-----	-	-	--	1	---	2	2	---	--	---	1	-----	2	2
Striking or bumping	---	--	---	2	-----	1	1	-	-	--	-----	---	---	-----	---	--	---	2	-----	1	1
Haulage	---	--	1	33	1,800	7	59	-	-	--	5	---	2	2	---	--	1	38	1,800	6	52
Explosives	---	--	1	9	1,800	40	216	-	-	--	-----	---	---	-----	---	--	1	9	1,800	40	216
Electricity	---	--	---	74	-----	2	2	-	-	--	2	---	5	5	---	--	---	76	-----	3	3
Machinery	---	--	1	116	1,800	9	24	-	-	--	21	---	4	4	---	--	1	137	1,800	8	21
Mine fires	---	--	---	1	-----	11	11	-	-	--	-----	---	---	-----	---	--	---	1	-----	11	11
All other	---	--	---	72	-----	6	6	-	-	--	8	---	2	2	---	--	---	80	-----	6	6
Total or average	---	--	6	511	1,800	11	32	-	-	--	91	---	4	4	---	--	6	602	1,800	10	28
Trunk:																					
Falls of roof	31	6	---	374	-----	67	601	1	-	--	12	---	101	554	32	6	---	386	-----	68	600
Falls of face or rib	3	--	1	80	600	59	277	3	-	--	16	---	53	992	6	--	1	96	600	58	409
Pressure bumps or bursts	---	--	---	2	-----	89	89	-	-	--	-----	---	---	-----	---	--	---	2	-----	89	89
Other falling objects	---	--	---	22	-----	47	47	-	-	--	12	---	38	38	---	--	---	34	-----	44	44
Falls of persons	1	1	1	278	700	33	78	-	-	--	93	---	19	19	1	1	1	371	700	30	64
Handling materials	---	--	4	950	445	28	30	-	-	--	59	---	21	21	---	--	4	1,009	445	28	29
Handtools	---	--	---	58	-----	30	30	-	-	--	7	---	18	18	---	--	---	65	-----	29	29
Stepping on objects	---	--	---	36	-----	40	40	-	-	--	2	---	47	47	---	--	---	38	-----	40	40
Striking or bumping	---	--	1	13	280	15	34	-	-	--	-----	---	---	-----	---	--	1	13	280	15	34
Haulage	11	4	2	638	1,450	38	179	1	-	--	42	---	29	168	12	4	2	680	1,450	38	178
Explosions (gas or dust)	3	--	---	-----	-----	---	6,000	-	-	--	-----	---	---	-----	3	--	---	------	-----	---	6,000
Explosives	---	--	---	15	-----	18	18	-	-	--	1	---	1	1	---	--	---	16	-----	17	17
Electricity	---	--	---	6	-----	17	17	-	-	--	-----	---	---	-----	---	--	---	6	-----	17	17
Machinery	2	--	1	333	1,500	37	77	-	-	--	21	---	32	32	2	--	1	354	1,500	37	74
Suffocation	---	--	---	4	-----	10	10	-	-	--	1	---	13	13	---	--	---	5	-----	11	11
Mine fires	10	--	---	22	-----	11	1,882	-	-	--	-----	---	---	-----	10	--	---	22	-----	11	1,882
All other	---	1	1	53	2,000	23	168	-	-	--	2	---	9	9	---	1	1	55	2,000	23	162
Total or average	61	12	11	2,884	887	38	188	5	-	--	268	---	29	138	66	12	11	3,152	887	37	183
Hernia:																					
Falls of persons	---	--	---	15	-----	49	49	-	-	--	2	---	48	48	---	--	---	17	-----	49	49
Handling materials	---	--	1	78	50	58	58	-	-	--	8	---	69	69	---	--	1	86	50	59	59
Handtools	---	--	---	2	-----	62	62	-	-	--	-----	---	---	-----	---	--	---	2	-----	62	62
Haulage	---	--	1	23	50	62	61	-	-	--	3	---	40	40	---	--	1	26	50	59	59
Machinery	---	--	---	17	-----	60	60	-	-	--	-----	---	---	-----	---	--	---	17	-----	60	60
All other	---	--	---	1	-----	91	91	-	-	--	-----	---	---	-----	---	--	---	1	-----	91	91
Total or average	---	--	2	136	50	58	58	-	-	--	13	---	59	59	---	--	2	149	50	58	58

TABLE 15. - Number of injuries and average severity by degree at coal mines in the United States, by part of body and major cause of injury, 1965--Continued

Major causes of injury	Bituminous-coal mines							Pennsylvania anthracite mines							All coal mines						
	Number of injuries				Average severity			Number of injuries				Average severity			Number of injuries				Average severity		
	Fatal	Permanent		Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent		Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent		Temporary total	Permanent partial	Temporary total	All injuries
		Total	Partial						Total	Partial						Total	Partial				
Arm:																					
Falls of roof	---	--	1	36	3,600	72	168	-	-	--	-----	---	---	---	---	--	1	36	3,600	72	168
Falls of face or rib	---	--	1	9	4,500	53	498	-	-	--	3	---	75	75	---	--	1	12	4,500	59	400
Pressure bumps or bursts	---	--	---	-----	-----	---	-----	-	-	--	1	---	258	258	---	--	---	1	-----	258	258
Other falling objects	---	--	---	8	-----	49	49	-	-	--	2	---	4	4	---	--	---	10	-----	40	40
Falls of persons	---	--	---	22	-----	34	34	-	-	--	10	---	16	16	---	--	---	32	-----	29	29
Handling materials	---	--	---	48	-----	27	27	-	-	--	3	---	13	13	---	--	---	51	-----	26	26
Handtools	---	--	---	24	-----	13	13	-	-	--	3	---	54	54	---	--	---	27	-----	17	17
Stepping on objects	---	--	---	2	-----	9	9	-	-	--	-----	---	---	---	---	--	---	2	-----	9	9
Haulage	---	--	4	96	3,030	51	170	-	-	--	4	---	23	23	---	--	4	100	3,030	49	164
Explosives	---	--	---	4	-----	39	39	-	-	--	-----	---	---	---	---	--	---	4	-----	39	39
Electricity	---	--	---	7	-----	8	8	-	-	--	-----	---	---	---	---	--	---	7	-----	8	8
Machinery	---	--	7	101	4,371	47	328	-	-	--	7	---	24	24	---	--	7	108	4,371	46	309
All other	---	--	---	1	-----	70	70	-	-	--	1	---	5	5	---	--	---	2	-----	38	38
Total or average	---	--	13	358	3,909	44	179	-	-	--	34	---	33	33	---	--	13	392	3,909	43	167
Hand and finger, including wrist:																					
Falls of roof	---	--	9	137	233	29	41	-	-	1	1	300	1	151	---	--	10	138	240	28	43
Falls of face or rib	---	--	5	25	245	36	71	-	-	1	9	50	103	98	---	--	6	34	213	54	78
Pressure bumps or bursts	---	--	---	1	-----	131	131	-	-	--	-----	---	---	---	---	--	---	1	-----	131	131
Other falling objects	---	--	3	44	228	26	39	-	-	1	26	200	21	28	---	--	4	70	221	24	35
Falls of persons	---	--	---	27	-----	25	25	-	-	--	18	---	27	27	---	--	---	45	-----	26	26
Handling materials	---	--	21	399	150	23	29	-	-	1	49	100	20	21	---	--	22	448	148	23	29
Handtools	---	--	6	96	237	17	30	-	-	--	13	---	18	18	---	--	6	109	237	17	29
Stepping on objects	---	--	---	4	-----	17	17	-	-	--	2	---	2	2	---	--	---	6	-----	12	12
Haulage	---	--	61	311	279	33	73	-	-	4	25	168	31	49	---	--	65	336	272	33	71
Explosives	---	--	1	---	1,740	---	1,740	-	-	--	-----	---	---	---	---	--	1	------	1,740	---	1,740
Electricity	---	--	---	99	-----	15	15	-	-	--	2	---	25	25	---	--	---	101	-----	15	15
Machinery	---	--	81	351	431	27	103	-	-	1	33	470	28	41	---	--	82	384	431	27	98
Mine fires	---	--	---	6	-----	34	34	-	-	--	-----	---	---	---	---	--	---	6	-----	34	34
All other	---	--	---	16	-----	8	8	-	-	--	3	---	15	15	---	--	---	19	-----	9	9
Total or average	---	--	187	1,516	333	26	59	-	-	9	181	199	27	35	---	--	196	1,697	327	26	57
Leg:																					
Falls of roof	1	--	---	142	-----	88	129	-	-	--	1	---	119	119	1	--	---	143	-----	88	129
Falls of face or rib	---	--	1	63	300	87	90	-	-	--	14	---	76	76	---	--	1	77	300	85	87
Pressure bumps or bursts	---	--	---	2	-----	30	30	-	-	--	2	---	213	213	---	--	---	4	-----	121	121
Other falling objects	---	--	---	15	-----	31	31	-	-	--	9	---	89	89	---	--	---	24	-----	53	53
Falls of persons	---	--	---	116	-----	35	35	-	-	--	38	---	32	32	---	--	---	154	-----	34	34
Handling materials	---	--	---	182	-----	41	41	-	-	--	24	---	48	48	---	--	---	206	-----	42	42
Handtools	---	--	---	31	-----	18	18	-	-	--	7	---	52	52	---	--	---	38	-----	24	24
Stepping on objects	---	--	1	93	120	29	30	-	-	--	7	---	12	12	---	--	1	100	120	28	29
Striking or bumping	---	--	---	12	-----	28	28	-	-	--	2	---	11	11	---	--	---	14	-----	26	26
Haulage	2	1	4	267	4,125	65	189	-	-	--	33	---	45	45	2	1	4	300	4,125	63	174
Explosives	---	--	---	18	-----	44	44	-	-	--	-----	---	---	---	---	--	---	18	-----	44	44
Electricity	---	--	---	12	-----	21	21	-	-	--	2	---	12	12	---	--	---	14	-----	20	20
Machinery	---	--	5	197	3,600	50	137	-	-	--	14	---	21	21	---	--	5	211	3,600	48	130
Mine fires	---	--	---	3	-----	7	7	-	-	--	-----	---	---	---	---	--	---	3	-----	7	7
All other	---	--	---	24	-----	32	32	-	-	--	4	---	23	23	---	--	---	28	-----	31	31
Total or average	3	1	11	1,177	3,175	53	102	-	-	--	157	---	45	45	3	1	11	1,334	3,175	52	95
Foot and toe, including ankle:																					
Falls of roof	---	--	2	198	450	46	50	-	-	--	-----	---	---	---	---	--	2	198	450	46	50
Falls of face or rib	---	--	1	35	70	44	45	-	-	--	9	---	39	39	---	--	1	44	70	43	44
Pressure bumps or bursts	---	--	---	2	-----	66	66	-	-	--	-----	---	---	---	---	--	---	2	-----	66	66
Other falling objects	---	--	---	43	-----	35	35	-	-	--	19	---	51	51	---	--	---	62	-----	40	40
Falls of persons	---	--	---	85	-----	33	33	-	-	--	17	---	50	50	---	--	---	102	-----	36	36
Handling materials	---	--	1	203	300	27	28	-	-	--	35	---	20	20	---	--	1	238	300	26	27
Handtools	---	--	---	23	-----	21	21	-	-	--	4	---	14	14	---	--	---	27	-----	20	20
Stepping on objects	---	--	---	63	-----	13	13	-	-	--	21	---	10	10	---	--	---	84	-----	12	12
Striking or bumping	---	--	---	1	-----	6	6	-	-	--	-----	---	---	---	---	--	---	1	-----	6	6
Haulage	---	--	8	212	1,014	47	82	-	-	--	18	---	63	63	---	--	8	230	1,014	48	81
Explosives	---	--	---	4	-----	99	99	-	-	--	-----	---	---	---	---	--	---	4	-----	99	99

TABLE 15. - Number of injuries and average severity by degree at coal mines in the United States, by part of body and major cause of injury, 1965--Continued

Major causes of injury	Bituminous-coal mines							Pennsylvania anthracite mines							All coal mines						
	Number of injuries				Average severity			Number of injuries				Average severity			Number of injuries				Average severity		
	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries	Fatal	Permanent Total	Permanent Partial	Temporary total	Permanent partial	Temporary total	All injuries
Foot and toe, including ankle (Continued):																					
Electricity	---	--	---	1	-----	24	24	-	-	--	-----	---	---	-----	---	--	---	1	-----	24	24
Machinery	1	--	7	180	920	41	105	-	-	2	12	260	48	78	1	--	9	192	773	41	104
All other	---	--	---	14	-----	17	17	-	-	--	-----	---	---	-----	---	--	---	14	-----	17	17
Total or average	1	--	19	1,064	833	37	57	-	-	2	135	260	36	39	1	--	21	1,199	778	37	55
Multiple:																					
Falls of roof	61	1	1	143	4,500	59	1,869	1	-	--	1	---	19	3,010	62	1	1	144	4,500	59	1,880
Falls of face or rib	6	--	---	29	-----	62	1,080	-	-	--	7	---	23	23	6	--	---	36	-----	55	904
Pressure bumps or bursts	1	--	---	2	-----	19	2,013	-	-	--	-----	---	---	-----	1	--	---	2	-----	19	2,013
Other falling objects	4	--	---	3	-----	12	3,434	-	-	--	1	---	23	23	4	--	---	4	-----	15	3,007
Falls of persons	3	--	---	20	-----	8	789	-	-	--	5	---	12	12	3	--	---	25	-----	9	651
Handling materials	---	--	---	26	-----	29	29	-	-	--	-----	---	---	-----	---	--	---	26	-----	29	29
Handtools	---	--	---	-----	-----	---	-----	-	-	--	1	---	16	16	---	--	---	1	-----	16	16
Stepping on objects	---	--	---	6	-----	31	31	-	-	--	-----	---	---	-----	---	--	---	6	-----	31	31
Striking or bumping	---	--	---	1	-----	27	27	-	-	--	-----	---	---	-----	---	--	---	1	-----	27	27
Haulage	18	1	---	95	-----	50	1,042	-	-	--	6	---	18	18	18	1	---	101	-----	48	990
Explosions (gas or dust)	16	--	---	11	-----	51	3,576	-	-	--	2	---	21	21	16	--	---	13	-----	46	3,331
Explosives	1	--	---	18	-----	45	359	-	-	--	4	---	7	7	1	--	---	22	-----	38	297
Electricity	9	--	---	83	-----	23	608	-	-	--	3	---	31	31	9	--	---	86	-----	23	590
Machinery	16	--	---	54	-----	49	1,409	-	-	--	6	---	23	23	16	--	---	60	-----	46	1,300
Mine fires	1	--	---	10	-----	21	565	-	-	--	-----	---	---	-----	1	--	---	10	-----	21	565
All other	1	--	---	12	-----	23	483	-	-	--	7	---	49	49	1	--	---	19	-----	32	331
Total or average	137	2	1	513	4,500	44	1,319	1	-	--	43	---	24	160	138	2	1	556	4,500	42	1,245
Not stated:																					
Falls of roof	---	--	---	221	-----	60	60	-	-	--	-----	---	---	-----	---	--	---	221	-----	60	60
Falls of face or rib	---	--	---	18	-----	57	57	-	-	--	-----	---	---	-----	---	--	---	18	-----	57	57
Other falling objects	---	--	---	9	-----	22	22	-	-	--	2	---	24	24	---	--	---	11	-----	22	22
Falls of persons	---	--	---	63	-----	34	34	-	-	--	9	---	24	24	---	--	---	72	-----	33	33
Handling materials	---	--	---	369	-----	28	28	-	-	--	17	---	14	14	---	--	---	386	-----	27	27
Handtools	---	--	---	41	-----	22	22	-	-	--	2	---	4	4	---	--	---	43	-----	21	21
Stepping on objects	---	--	---	17	-----	30	30	-	-	--	-----	---	---	-----	---	--	---	17	-----	30	30
Haulage	---	--	---	155	-----	48	48	-	-	--	3	---	66	66	---	--	---	158	-----	48	48
Explosives	---	--	---	2	-----	11	11	-	-	--	-----	---	---	-----	---	--	---	2	-----	11	11
Electricity	---	--	---	19	-----	13	13	-	-	--	-----	---	---	-----	---	--	---	19	-----	13	13
Machinery	---	--	---	154	-----	43	43	-	-	--	6	---	15	15	---	--	---	160	-----	42	42
All other	---	--	---	3	-----	19	19	-	-	--	-----	---	---	-----	---	--	---	3	-----	19	19
Total or average	---	--	---	1,071	-----	40	40	-	-	--	39	---	20	20	---	--	---	1,110	-----	39	39
Grand total or average	251	16	252	9,803	752	37	208	8	-	11	1,056	210	29	75	259	16	263	10,859	730	36	196

TABLE 16. - Number of injuries, average severity, and injury rates at bituminous-coal mines, by nature of injury, 1965

General work location and nature of injury	Number of injuries						Distribution of all injuries, percent	Average severity			Severity rates per million man-hours		Frequency rates per million man-hours	
	Fatal	Nonfatal				All injuries		Permanent partial	Temporary total	All injuries	Fatal	Nonfatal	Fatal	Nonfatal
		Permanent		Temporary total	Total nonfatal									
		Total	Partial											
Underground mines:														
Underground (including shaft and slope):														
Amputation and enucleation	1	--	169	-----	169	170	2.5	740	--	771	39	817	0.01	1.10
Asphyxiation	8	--	---	26	26	34	.5	-----	11	1,420	314	2	.05	.17
Crushing, contusion, or bruise	127	3	4	2,003	2,010	2,137	31.7	130	25	389	4,980	450	.83	13.14
Burn or scald (except chemical)	13	--	---	291	291	304	4.5	-----	15	271	510	28	.08	1.90
Chemical burn	7	--	---	25	25	32	.5	-----	19	1,327	274	3	.05	.16
Radiations and radiating substances	---	--	---	27	27	27	.4	-----	4	4	-----	1	----	.18
Cut, laceration, or puncture	2	--	5	820	825	827	12.3	104	25	40	78	136	.01	5.39
Electric shock	4	--	---	20	20	24	.4	-----	10	1,009	157	1	.03	.13
Foreign body in eye	---	--	1	134	135	135	2.0	1,800	13	27	-----	23	----	.88
Fracture	23	8	9	1,267	1,284	1,307	19.4	1,228	82	231	902	1,067	.15	8.39
Hernia	---	--	1	89	90	90	1.3	50	62	62	-----	36	----	.59
Poisoning (systemic)	3	--	---	3	3	6	.1	-----	6	3,003	118	(1/)	.02	.02
Strain, sprain, and dislocation	---	2	5	1,513	1,520	1,520	22.6	416	33	42	-----	422	----	9.93
Pneumoconiosis	---	--	---	1	1	1	(2/)	-----	34	34	-----	(1/)	----	.01
Inflammation or irritation of joints, tendons, or muscles	---	--	1	3	4	4	.1	120	20	45	-----	1	----	.03
Other, not elsewhere classified	5	1	---	116	117	122	1.8	-----	48	340	196	75	.03	.76
Unclassified - no data	22	--	4	1,400	1,404	1,426	-----	449	40	133	863	374	.14	9.18
Total or average	215	14	199	7,738	7,951	8,166	-----	719	39	222	8,430	3,437	1.41	51.96
Surface:														
Amputation and enucleation	---	1	24	-----	25	25	2.7	877	--	1,082	-----	757	----	.70
Crushing, contusion, or bruise	9	--	---	179	179	188	20.5	-----	20	306	1,511	99	.25	5.01
Burn or scald (except chemical)	1	--	---	43	43	44	4.8	-----	25	161	168	31	.03	1.20
Chemical burn	---	--	---	9	9	9	1.0	-----	16	16	-----	4	----	.25
Radiations and radiating substances	---	--	---	8	8	8	.9	-----	5	5	-----	1	----	.22
Cut, laceration, or puncture	---	--	---	117	117	117	12.8	-----	21	21	-----	69	----	3.27
Electric shock	2	--	---	1	1	3	.3	-----	24	4,008	336	1	.06	.03
Foreign body in eye	---	--	---	30	30	30	3.3	-----	8	8	-----	7	----	.84
Fracture	2	--	---	150	150	152	16.6	-----	80	157	336	334	.06	4.20
Hernia	---	--	---	26	26	26	2.8	-----	51	51	-----	37	----	.73
Poisoning (systemic)	---	--	---	1	1	1	.1	-----	3	3	-----	(1/)	----	.03
Strain, sprain, and dislocation	---	--	---	296	296	296	32.3	-----	26	26	-----	212	----	8.28
Silicosis	---	--	1	-----	1	1	.1	2,000	--	2,000	-----	56	----	.03
Other, not elsewhere classified	2	--	---	15	15	17	1.9	-----	35	737	336	15	.06	.42
Unclassified - no data	1	--	---	108	108	109	-----	-----	27	82	168	82	.03	3.02
Total or average	17	1	25	983	1,009	1,026	-----	922	32	159	2,855	1,704	.48	28.24
Total or average, underground mines	232	15	224	8,721	8,960	9,192	-----	741	38	215	7,375	3,109	1.23	47.47

See footnotes at end of table.

TABLE 16. - Number of injuries, average severity, and injury rates at bituminous-coal mines, by nature of injury, 1965--Continued

General work location and nature of injury	Number of injuries						Distribution of all injuries, percent	Average severity			Severity rates per million man-hours		Frequency rates per million man-hours	
	Fatal	Nonfatal				All injuries		Permanent partial	Temporary total	All injuries	Fatal	Nonfatal	Fatal	Nonfatal
		Permanent		Temporary total	Total nonfatal									
		Total	Partial											
Strip mines:														
Amputation and enucleation	---	--	23	-----	23	23	2.6	840	--	840	-----	466	----	.55
Asphyxiation	1	--	---	-----	------	1	.1	-----	--	6,000	145	-----	.02	-----
Crushing, contusion, or bruise	11	--	1	181	182	193	21.6	600	19	363	1,591	99	.27	4.39
Burn or scald (except chemical)	---	--	---	35	35	35	3.9	-----	24	24	-----	20	----	.84
Chemical burn	---	--	---	7	7	7	.8	-----	5	5	-----	1	----	.17
Radiations and radiating substances	---	--	---	12	12	12	1.3	-----	4	4	-----	1	----	.29
Cut, laceration, or puncture	---	--	---	105	105	105	11.8	-----	15	15	-----	38	----	2.53
Electric shock	3	--	---	1	1	4	.4	-----	10	4,503	434	(1/)	.07	.02
Foreign body in eye	---	--	1	36	37	37	4.1	1,800	9	58	-----	51	----	.89
Fracture	3	--	---	135	135	138	15.5	-----	50	180	434	164	.07	3.25
Hernia	---	--	1	21	22	22	2.5	50	52	52	-----	28	----	.53
Poisoning (systemic)	---	--	---	1	1	1	.1	-----	1	1	-----	(1/)	----	.02
Strain, sprain, and dislocation	---	--	1	279	280	280	31.4	700	18	21	-----	141	----	6.75
Concussion - brain, cerebral	---	--	---	1	1	1	.1	-----	44	44	-----	1	----	.02
Other, not elsewhere classified	---	1	---	33	34	34	3.8	-----	35	211	-----	173	----	.82
Unclassified - no data	---	--	---	157	157	157	-----	-----	28	28	-----	107	----	3.78
Total or average	18	1	27	1,004	1,032	1,050	-----	832	25	154	2,604	1,291	.43	24.88
Auger mines:														
Amputation and enucleation	---	--	1	-----	1	1	2.0	1,140	--	1,140	-----	479	----	.42
Crushing, contusion, or bruise	1	--	---	17	17	18	36.0	-----	34	365	2,521	243	.42	7.14
Burn or scald (except chemical)	---	--	---	3	3	3	6.0	-----	3	3	-----	4	----	1.26
Radiations and radiating substances	---	--	---	1	1	1	2.0	-----	1	1	-----	(1/)	----	.42
Cut, laceration, or puncture	---	--	---	7	7	7	14.0	-----	26	26	-----	76	----	2.94
Foreign body in eye	---	--	---	1	1	1	2.0	-----	1	1	-----	(1/)	----	.42
Fracture	---	--	---	5	5	5	10.0	-----	29	29	-----	61	----	2.10
Strain, sprain, and dislocation	---	--	---	13	13	13	26.0	-----	48	48	-----	263	----	5.46
Other, not elsewhere classified	---	--	---	1	1	1	2.0	-----	96	96	-----	40	----	.42
Unclassified - no data	---	--	---	30	30	30	-----	-----	32	32	-----	401	----	12.61
Total or average	1	--	1	78	79	80	-----	1,140	33	122	2,521	1,568	.42	33.20
Grand total or average	251	16	252	9,803	10,071	10,322	-----	752	37	208	6,474	2,769	1.08	43.30

1/ Less than 0.5
2/ Less than 0.05

TABLE 17. - Number of injuries, average severity, and injury rates at Pennsylvania anthracite mines, by nature of injury, 1965

General work location and nature of injury	Number of injuries						Distribution of all injuries, percent	Average severity			Severity rates per million man-hours		Frequency rates per million man-hours	
	Fatal	Nonfatal				All injuries		Permanent partial	Temporary total	All injuries	Fatal	Nonfatal	Fatal	Nonfatal
		Permanent		Temporary total	Total nonfatal									
		Total	Partial											
Underground mines:														
Underground (including shaft and slope):														
Amputation and enucleation	-	--	8	---	8	8	1.2	211	--	211	-----	262	----	1.24
Asphyxiation	2	--	--	---	---	2	.3	---	--	6,000	1,862	-----	0.31	------
Crushing, contusion, or bruise	2	--	--	204	204	206	30.8	---	15	73	1,862	481	.31	31.66
Burn or scald (except chemical)	-	--	--	10	10	10	1.5	---	21	21	-----	33	----	1.55
Chemical burn	-	--	--	1	1	1	.1	---	17	17	-----	3	----	.16
Radiations and radiating substances	-	--	--	2	2	2	.3	---	4	4	-----	1	----	.31
Cut, laceration, or puncture	-	--	--	181	181	181	27.1	---	16	16	-----	454	----	28.09
Drowning	1	--	--	---	---	1	.1	---	--	6,000	931	-----	.16	------
Foreign body in eye	-	--	--	38	38	38	5.7	---	4	4	-----	23	----	5.90
Fracture	2	--	--	113	113	115	17.2	---	96	199	1,862	1,687	.31	17.54
Hernia	-	--	--	4	4	4	.6	---	42	42	-----	26	----	.62
Strain, sprain, and dislocation	-	--	--	90	90	90	13.5	---	20	20	-----	281	----	13.97
Other - not elsewhere classified	-	--	--	10	10	10	1.5	---	8	8	-----	13	----	1.55
Unclassified - no data	1	--	--	39	39	40	----	---	18	168	931	110	.16	6.05
Total or average	8	--	8	692	700	708	----	211	29	98	7,449	3,373	1.24	108.63
Surface (including culm banks, dredges, and preparation plants):														
Amputation and enucleation	-	--	3	1	4	4	1.9	207	71	173	-----	110	----	.63
Asphyxiation	-	--	--	1	1	1	.5	---	13	13	-----	2	----	.16
Crushing, contusion, or bruise	-	--	--	53	53	53	25.3	---	31	31	-----	257	----	8.40
Burn or scald (except chemical)	-	--	--	9	9	9	4.3	---	23	23	-----	33	----	1.43
Radiations and radiating substances	-	--	--	2	2	2	1.0	---	3	3	-----	1	----	.32
Cut, laceration, or puncture	-	--	--	24	24	24	11.5	---	23	23	-----	89	----	3.81
Foreign body in eye	-	--	--	13	13	13	6.2	---	4	4	-----	7	----	2.06
Fracture	-	--	--	44	44	44	21.0	---	57	57	-----	396	----	6.98
Hernia	-	--	--	6	6	6	2.9	---	74	74	-----	70	----	.95
Strain, sprain, and dislocation	-	--	--	52	52	52	24.9	---	25	25	-----	209	----	8.25
Other - not elsewhere classified	-	--	--	1	1	1	.5	---	4	4	-----	1	----	.16
Unclassified - no data	-	--	--	12	12	12	----	---	13	13	-----	25	----	1.90
Total or average	-	--	3	218	221	221	----	207	32	34	-----	1,200	----	35.04
Total or average, underground mines	8	--	11	910	921	929	----	210	30	83	3,765	2,298	.63	72.23

TABLE 17. - Number of injuries, average severity, and injury rates at Pennsylvania anthracite mines, by nature of injury, 1965--Continued

General work location and nature of injury	Number of injuries						Distribution of all injuries, percent	Average severity			Severity rates per million man-hours		Frequency rates per million man-hours	
	Fatal	Nonfatal				All injuries		Permanent partial	Temporary total	All injuries				
		Permanent		Temporary total	Total nonfatal									
		Total	Partial								Fatal	Nonfatal	Fatal	Nonfatal
Strip mines:														
Crushing, contusion, or bruise	-	--	--	36	36	36	31.0	---	25	25	-----	252	----	9.93
Burn or scald (except chemical)	-	--	--	6	6	6	5.2	---	39	39	-----	65	----	1.66
Chemical burn	-	--	--	2	2	2	1.7	---	9	9	-----	5	----	.55
Radiations and radiating substances	-	--	--	2	2	2	1.7	---	44	44	-----	24	----	.55
Cut, laceration, or puncture	-	--	--	19	19	19	16.4	---	13	13	-----	69	----	5.24
Foreign body in eye	-	--	--	3	3	3	2.6	---	3	3	-----	3	----	.83
Fracture	-	--	--	11	11	11	9.5	---	72	72	-----	220	----	3.03
Hernia	-	--	--	3	3	3	2.6	---	52	52	-----	43	----	.83
Poisoning (systemic)	-	--	--	1	1	1	.9	---	12	12	-----	3	----	.28
Strain, sprain, and dislocation	-	--	--	32	32	32	27.6	---	14	14	-----	127	----	8.83
Other - not elsewhere classified	-	--	--	1	1	1	.9	---	1	1	-----	(1/)	----	.28
Unclassified - no data	-	--	--	30	30	30	----	---	19	19	-----	161	----	8.28
Total or average	-	--	--	146	146	146	----	---	24	24	-----	971	----	40.28
Grand total or average	8	--	11	1,056	1,067	1,075	----	210	29	75	2,931	2,004	.49	65.16

1/ Less than 0.5.

TABLE 18. - Closed cases 1/ of temporary total injuries for which company reported days of disability at bituminous-coal mines in the United States, by days of disability per injury and general work location, 1965

Days of disability per injury	Number of temporary total injuries					
	Underground mines			Strip mines	Auger mines	Total
	Underground	Surface	Total			
1	414	72	486	110	4	600
2	263	58	321	80	1	402
3	328	51	379	60	3	442
4	316	39	355	62	2	419
5	301	34	335	44	1	380
6	278	41	319	44	2	365
7	180	17	197	26	3	226
8	116	27	143	17	-	160
9	158	21	179	30	2	211
10	168	25	193	21	1	215
11	175	17	192	22	-	214
12	162	23	185	12	1	198
13	171	32	203	19	1	223
14	90	15	105	13	1	119
15	87	8	95	6	-	101
16	93	12	105	10	2	117
17	120	16	136	8	1	145
18	106	6	112	12	-	124
19	90	9	99	5	1	105
20	116	16	132	6	-	138
21	70	5	75	9	-	84
22	48	4	52	3	-	55
23	61	4	65	6	1	72
24	70	10	80	7	1	88
25	63	19	82	8	3	93
26	76	13	89	9	-	98
27	83	7	90	6	1	97
28	47	10	57	10	1	68
29	36	4	40	7	-	47
30	54	7	61	4	-	65
31	61	8	69	6	1	76
32	63	4	67	3	-	70
33	56	7	63	4	1	68
34	59	10	69	5	1	75
35	48	5	53	3	-	56
36	23	4	27	6	-	33
37	38	7	45	5	1	51
38	38	2	40	10	-	50
39	37	4	41	2	-	43
40	35	2	37	4	1	42
41	51	1	52	5	-	57
42	36	2	38	2	-	40
43	16	3	19	2	-	21
44	37	2	39	5	1	45
45	34	5	39	4	-	43
46-60	409	47	456	46	2	504
61-90	430	53	483	35	-	518
91-120	211	31	242	23	1	266
121-150	131	14	145	3	-	148
151 or more	328	34	362	26	2	390
Total	6,481	867	7,348	875	44	8,267

1/ In addition to the temporary total injuries for which companies reported days of disability, there were 1,536 temporary total injuries for which days of disability were not reported. To obtain total severity data for the industry, these "open cases" were closed by assigning average days of disability by classification.

TABLE 19. - Closed cases 1/ of temporary total injuries for which company reported days of disability at Pennsylvania anthracite mines, by days of disability per injury and general work location, 1965

Days of disability per injury	Number of temporary total injuries				
	Underground mines			Strip mines	Total
	Underground	Surface 2/	Total		
1	45	15	60	10	70
2	60	13	73	11	84
3	51	9	60	5	65
4	51	13	64	7	71
5	43	10	53	11	64
6	34	15	49	3	52
7	14	2	16	4	20
8	4	3	7	2	9
9	15	4	19	3	22
10	17	1	18	4	22
11	12	6	18	5	23
12	14	1	15	2	17
13	14	4	18	3	21
14	6	1	7	1	8
15	7	3	10	6	16
16	3	6	9	4	13
17	11	7	18	3	21
18	17	2	19	---	19
19	4	---	4	3	7
20	6	4	10	2	12
21	2	2	4	---	4
22	5	2	7	1	8
23	2	2	4	2	6
24	5	3	8	---	8
25	10	2	12	---	12
26	4	---	4	1	5
27	6	1	7	---	7
28	6	2	8	---	8
29	4	---	4	---	4
30	3	1	4	1	5
31	4	---	4	---	4
32	9	1	10	2	12
33	5	1	6	1	7
34	3	2	5	---	5
35	3	---	3	1	4
36	1	---	1	1	2
37	2	1	3	---	3
38	1	1	2	---	2
39	1	---	1	1	2
40	1	1	2	1	3
41	1	---	1	1	2
42	5	5	10	---	10
43	1	---	1	---	1
44	1	1	2	---	2
45	1	1	2	1	3
46-60	30	11	41	5	46
61-90	21	16	37	7	44
91-120	15	3	18	1	19
121-150	5	4	9	---	9
151 or more	26	5	31	4	35
Total	611	187	798	120	918

1/ In addition to the temporary total injuries for which companies reported days of disability, there were 138 temporary total injuries for which days of disability were not reported. To obtain total severity data for the industry these "open cases" were closed by assigning average days of disability by classification.

2/ Includes injuries for culm banks, dredges, preparation plants, and general repair shops.

TABLE 20. - Employment and production data on bituminous-coal mines (underground and surface works) in the United States, by percentage of coal loaded mechanically, 1965

Coal loaded mechanically, percent	Number of mines	Men at work	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour
All hand loading	3,709	21,766	3,438,633	27,324,819	31,150,699	1.14
1 to 19	12	112	23,905	187,212	303,791	1.62
20 to 39	24	260	51,147	408,946	425,743	1.04
40 to 59	24	461	95,335	757,664	579,558	.76
60 to 79	23	273	60,747	485,118	470,701	.97
80 to 99	38	851	198,641	1,575,060	2,213,846	1.41
100	1,587	82,242	18,524,952	147,381,779	291,990,522	1.98
Not stated	812	4,571	622,060	4,917,537	5,535,974	1.13
Surface 1/	-----	3,115	771,027	5,714,870	-----------	----
Total or average	6,229	113,651	23,786,447	188,753,005	332,670,834	1.76

1/ Data on 73 surface installations (preparation plants and general repair shops) that could not be assigned to any single underground mine.

TABLE 21. - Employment and production data on Pennsylvania anthracite mines (underground and surface works) by percentage of coal loaded mechanically, 1965

Coal loaded mechanically, percent	Number of mines	Men at work	Man-days worked	Man-hours worked	Production, short tons	Ton per man-hour
All hand loading	352	1,529	286,081	1,946,963	1,296,076	0.67
1 to 19	3	27	7,884	53,988	46,200	.86
20 to 39	5	57	9,974	69,338	33,929	.49
40 to 59	8	110	22,761	149,744	146,558	.98
60 to 79	9	133	23,328	163,698	115,488	.71
80 to 99	8	299	50,651	354,023	159,915	.45
100	42	2,318	529,802	3,919,644	2,457,501	.63
Not stated	210	1,221	220,443	1,552,234	1,050,548	.68
Surface 1/	---	379	99,779	724,243	---------	----
Total or average	637	6,073	1,250,703	8,933,875	5,306,215	.59

1/ Data on 13 general repair shops that could not be assigned to any single underground mine.

TABLE 22. - Injury experience at bituminous-coal mines (underground and surface works) in the United States, by percentage of coal loaded mechanically, 1965

Coal loaded mechanically, percent	Number of injuries						Distribution of all injuries, percent	Average severity			Severity rates per million man-hours		Frequency rates per million man-hours	
	Fatal	Nonfatal				All injuries		Permanent partial	Temporary total	All injuries	Fatal	Nonfatal	Fatal	Nonfatal
		Permanent		Temporary total	Total nonfatal									
		Total	Partial											
All hand loading	30	1	20	1,146	1,167	1,197	13.4	1,109	36	209	6,587	2,557	1.10	42.71
1 to 19	---	--	1	25	26	26	.3	75	37	38	------	5,304	----	138.88
20 to 39	1	--	---	32	32	33	.4	-----	34	214	14,672	2,636	2.45	78.25
40 to 59	---	--	---	57	57	57	.6	-----	38	38	------	2,846	----	75.23
60 to 79	3	--	2	47	49	52	.6	188	29	380	37,104	3,589	6.18	101.01
80 to 99	1	--	2	130	132	133	1.5	420	23	74	3,809	2,410	.63	83.81
100	182	14	191	7,045	7,250	7,432	83.2	728	38	213	7,409	3,349	1.23	49.19
Not stated	13	--	4	172	176	189	-----	250	40	454	15,862	1,585	2.64	35.79
Surface 1/	2	--	4	67	71	73	-----	613	50	243	2,100	1,011	.35	12.42
Total or average	232	15	224	8,721	8,960	9,192	-----	741	38	215	7,375	3,109	1.23	47.47

1/ Data on 73 surface installations (preparation plants and general repair shops) that could not be assigned to any single underground mine.

TABLE 23. - Injury experience at Pennsylvania anthracite mines (underground and surface works), by percentage of coal loaded mechanically, 1965

Coal loaded mechanically, percent	Number of injuries						Distribution of all injuries, percent	Average severity			Severity rates per million man-hours		Frequency rates per million man-hours	
	Fatal	Nonfatal				All injuries		Permanent partial	Temporary total	All injuries	Fatal	Nonfatal	Fatal	Nonfatal
		Permanent		Temporary total	Total nonfatal									
		Total	Partial											
All hand loading	2	-	1	77	78	80	12.5	300	28	180	6,163	1,252	1.03	40.06
1 to 19	2	-	-	5	5	7	1.1	---	21	1,729	222,272	1,926	37.05	92.61
20 to 39	-	-	-	---	---	---	-----	---	--	-----	-------	-------	-----	------
40 to 59	-	-	2	30	32	32	5.0	260	44	57	-------	12,281	-----	213.70
60 to 79	-	-	-	13	13	13	2.0	---	27	27	-------	2,114	-----	79.41
80 to 99	1	-	-	14	14	15	2.3	---	15	414	16,948	585	2.82	39.55
100	2	-	5	487	492	494	77.1	174	30	56	3,062	4,006	.51	125.52
Not stated	1	-	-	97	97	98	-----	---	24	85	3,865	1,528	.64	62.49
Surface 1/	-	-	-	14	14	14	-----	---	20	20	-------	389	-----	19.33
Total or average	8	-	8	737	745	753	-----	211	29	95	5,373	2,607	.90	83.39

1/ Data on 13 general repair shops that could not be assigned to any single underground mine.

TABLE 24. - Injury experience, employment, and production data on bituminous-coal mines in the United States, by number of men employed, 1965

Number of men employed	Number of injuries		Frequency rates: Per million man-hours		Frequency rates: Per million tons		Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour	Number of mines
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal							
Underground mines (includes surface works):													
1 to 4	13	377	1.43	41.47	1.01	29.20	8,230	140	1,149,923	9,090,374	12,912,958	1.42	2,823
5 to 9	25	475	1.86	35.25	1.52	28.85	11,710	145	1,692,434	13,474,118	16,465,774	1.22	1,773
10 to 19	31	823	1.97	52.40	1.45	38.58	11,459	172	1,971,634	15,705,863	21,333,291	1.36	884
20 to 49	20	1,134	1.23	69.86	.73	41.17	10,915	187	2,036,796	16,231,907	27,546,975	1.70	367
50 to 99	32	1,033	2.11	68.20	1.15	37.20	8,915	213	1,899,180	15,146,610	27,769,364	1.83	129
100 to 249	50	3,088	.99	61.01	.50	30.89	27,110	235	6,377,913	50,616,841	99,976,255	1.98	170
250 or more	59	1,959	.94	31.21	.47	15.47	32,197	245	7,887,540	62,772,422	126,666,217	2.02	83
Surface 1/	2	71	.35	12.42	----	-----	3,115	248	771,027	5,714,870	-----------	----	-----
Total or average	232	8,960	1.23	47.47	.70	26.93	113,651	209	23,786,447	188,753,005	332,670,834	1.76	6,229
Strip mines:													
1 to 4	1	45	.48	21.51	.14	6.22	1,580	159	250,714	2,091,843	7,228,916	3.46	608
5 to 9	--	80	----	19.97	----	6.46	2,607	182	474,956	4,005,229	12,382,883	3.09	397
10 to 19	3	146	.36	17.62	.12	5.69	4,524	221	1,001,595	8,286,708	25,645,511	3.09	331
20 to 49	5	180	.58	20.91	.17	6.12	4,447	233	1,037,717	8,607,312	29,413,533	3.42	153
50 to 99	2	254	.23	29.54	.05	6.46	4,230	262	1,107,135	8,599,201	39,320,533	4.57	62
100 or more	7	327	.71	33.06	.13	6.27	4,477	289	1,295,239	9,889,897	52,136,123	5.27	31
Total or average	18	1,032	.43	24.88	.11	6.21	21,865	236	5,167,356	41,480,190	166,127,499	4.00	1,582
Auger mines:													
1 to 4	-	30	----	46.52	----	6.35	640	120	76,805	644,920	4,725,615	7.33	235
5 to 9	-	14	----	17.73	----	3.13	725	131	94,911	789,742	4,469,304	5.66	113
10 to 19	1	30	1.42	42.58	.25	7.59	554	156	86,530	704,528	3,953,308	5.61	43
20 to 49	-	5	----	20.78	----	4.40	167	179	29,886	240,635	1,137,144	4.73	6
50 or more	-	--	----	-----	----	-----	-----	---	-------	---------	----------	----	---
Total or average	1	79	.42	33.20	.07	5.53	2,086	138	288,132	2,379,825	14,285,371	6.00	397

1/ Data on 73 surface installations (preparation plants and general repair shops) that could not be assigned to any single underground mine.

TABLE 25. - Injury experience, employment, and production data on Pennsylvania anthracite mines, by number of men employed, 1965

Number of men employed	Number of injuries		Frequency rates				Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour	Number of mines
			Per million man-hours		Per million tons								
	Fatal	Non-fatal	Fatal	Non-fatal	Fatal	Non-fatal							
Underground mines (includes surface works):													
1 to 4	2	12	1.42	8.54	2.61	15.65	1,368	151	207,020	1,405,303	766,647	0.55	468
5 to 9	1	30	1.07	32.20	1.32	39.61	607	225	136,296	931,773	757,453	.81	97
10 to 19	2	66	2.22	73.38	2.71	89.29	540	244	131,498	899,475	739,187	.82	42
20 to 49	-	84	----	128.80	----	159.98	432	216	93,496	652,175	525,055	.81	15
50 to 99	-	79	----	129.68	----	210.45	489	162	79,200	609,187	375,394	.62	7
100 to 249	1	140	.90	126.02	1.15	160.34	682	227	155,132	1,110,913	873,145	.79	4
250 or more	2	320	.77	123.04	1.58	252.10	1,576	221	348,282	2,600,806	1,269,334	.49	4
Surface 1/	-	14	----	19.33	----	------	379	263	99,779	724,243	---------	----	---
Total or average	8	745	.90	83.39	1.51	140.40	6,073	206	1,250,703	8,933,875	5,306,215	.59	637
Strip mines:													
1 to 4	-	5	----	30.19	----	22.40	205	111	22,660	165,636	223,253	1.35	85
5 to 9	-	8	----	24.36	----	17.91	254	178	45,280	328,394	446,780	1.36	39
10 to 19	-	42	----	59.41	----	34.81	476	208	99,161	706,914	1,206,437	1.71	33
20 to 49	-	40	----	41.72	----	19.93	639	212	135,517	958,775	2,007,023	2.09	22
50 to 99	-	37	----	33.41	----	25.87	560	282	157,736	1,107,404	1,430,038	1.29	7
100 to 249	-	14	----	39.13	----	21.47	215	231	49,718	357,750	651,950	1.82	2
Total or average	-	146	----	40.28	----	24.47	2,349	217	510,072	3,624,873	5,965,481	1.65	188
Culm banks:													
1 to 4	-	2	----	19.04	----	3.03	138	103	14,243	105,028	660,784	6.29	51
5 to 9	-	4	----	20.89	----	3.02	256	101	25,960	191,441	1,325,697	6.92	40
10 to 19	-	7	----	48.16	----	8.77	147	142	20,843	145,335	797,779	5.49	12
20 to 49	-	---	----	------	----	------	25	252	6,300	44,100	152,924	3.47	1
Total or average	-	13	----	26.75	----	4.43	566	119	67,346	485,904	2,937,184	6.04	104
Dredges:													
1 to 4	-	---	----	------	----	------	32	143	4,572	37,855	77,471	2.05	12
10 to 19	-	---	----	------	----	------	13	281	3,653	29,224	65,657	2.25	1
50 to 99	-	1	----	7.97	----	1.79	52	302	15,687	125,496	557,329	4.44	1
Total or average	-	1	----	5.19	----	1.43	97	247	23,912	192,575	700,457	3.64	14
Preparation plants:													
1 to 4	-	6	----	28.43	----	------	136	203	27,580	211,055	---------	----	---
5 to 9	-	14	----	41.42	----	------	216	199	42,928	338,020	---------	----	---
10 to 19	-	19	----	28.49	----	------	431	208	89,457	666,925	---------	----	---
20 to 49	-	58	----	64.04	----	------	556	223	123,796	905,737	---------	----	---
50 to 99	-	65	----	63.95	----	------	708	191	135,408	1,016,395	---------	----	---
Total or average	-	162	----	51.62	----	------	2,047	205	419,169	3,138,132	---------	----	---

1/ Data on 13 general repair shops that could not be assigned to any single underground mine.

TABLE 26. - Injury experience, employment, and production data on bituminous-coal mines in the United States, by length of shift, 1965

Length of shift, hours	Number of injuries		Frequency rates: Per million man-hours		Frequency rates: Per million tons		Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour	Number of mines
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal							
Underground mines (includes surface works):													
5.5 to 6.4	---	5	----	32.09	----	36.09	200	129	25,860	155,830	138,552	0.89	82
6.5 to 7.4	6	165	1.06	29.25	2.45	67.37	3,571	220	783,933	5,640,345	2,449,142	.43	257
7.5 to 8.4	217	8,457	1.24	48.28	.69	26.72	106,051	208	22,080,273	175,173,123	316,485,441	1.81	5,819
8.5 to 9.4	8	306	1.08	41.43	.62	23.66	3,562	239	849,999	7,386,642	12,935,760	1.75	34
All other	1	27	2.52	68.00	1.51	40.79	267	174	46,382	397,065	661,939	1.67	37
Total or average	232	8,960	1.23	47.47	.70	26.93	113,651	209	23,786,447	188,753,005	332,670,834	1.76	6,229
Strip mines:													
5.5 to 6.4	--	4	----	28.90	----	12.96	77	306	23,591	138,402	308,648	2.23	11
6.5 to 7.4	3	229	.38	29.16	.07	5.33	4,111	263	1,079,969	7,853,946	42,963,330	5.47	94
7.5 to 8.4	12	639	.47	24.92	.12	6.46	14,032	230	3,226,133	25,642,326	98,854,551	3.86	1,147
8.5 to 9.4	1	107	.22	24.01	.07	7.89	2,046	244	498,777	4,456,921	13,561,587	3.04	173
All other	2	53	.59	15.64	.19	5.08	1,599	212	338,886	3,388,595	10,439,383	3.08	157
Total or average	18	1,032	.43	24.88	.11	6.21	21,865	236	5,167,356	41,480,190	166,127,499	4.00	1,582
Auger mines:													
5.5 to 6.4	-	--	----	-----	----	----	-----	---	-------	---------	----------	----	---
6.5 to 7.4	-	5	----	17.04	----	2.95	252	160	40,424	293,381	1,694,113	5.77	30
7.5 to 8.4	1	51	.68	34.60	.11	5.69	1,393	132	184,281	1,473,800	8,963,527	6.08	283
8.5 to 9.4	-	9	----	55.87	----	9.60	108	169	18,268	161,098	937,385	5.82	23
All other	-	14	----	31.00	----	5.20	333	136	45,159	451,546	2,690,346	5.96	61
Total or average	1	79	.42	33.20	.07	5.53	2,086	138	288,132	2,379,825	14,285,371	6.00	397

TABLE 27. - Injury experience, employment, and production data on Pennsylvania anthracite mines, by length of shift, 1965

Length of shift, hours	Number of injuries		Frequency rates				Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour	Number of mines
			Per million man-hours		Per million tons								
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal							
Underground mines (includes surface works):													
5.5 to 6.4 ----------------	1	8	1.80	14.43	2.06	16.44	429	212	90,976	554,323	486,519	0.88	93
6.5 to 7.4 ----------------	7	642	1.02	93.84	1.60	146.75	4,666	205	955,531	6,841,140	4,374,929	.64	459
7.5 to 8.4 ----------------	-	40	----	101.74	----	174.53	272	184	50,011	393,164	229,190	.58	54
8.5 to 9.4 ----------------	-	38	----	111.88	----	219.32	246	161	39,573	339,658	173,264	.51	5
All other -----------------	-	3	----	36.88	----	70.90	81	183	14,833	81,347	42,313	.52	26
Surface 1/ ----------------	-	14	----	19.33	----	------	379	263	99,779	724,243	---------	----	---
Total or average --------	8	745	.90	83.39	1.51	140.40	6,073	206	1,250,703	8,933,875	5,306,215	.59	637
Strip mines:													
5.5 to 6.4 ----------------	-	6	----	76.20	----	22.85	64	216	13,849	78,741	262,554	3.33	6
6.5 to 7.4 ----------------	-	115	----	37.40	----	23.28	1,941	225	437,120	3,074,832	4,940,017	1.61	135
7.5 to 8.4 ----------------	-	22	----	49.97	----	33.90	289	193	55,790	440,260	648,978	1.47	41
8.5 to 9.4 ----------------	-	3	----	108.38	----	27.87	53	56	2,977	27,680	107,653	3.89	5
All other -----------------	-	---	----	------	----	------	2	168	336	3,360	6,279	1.87	1
Total or average --------	-	146	----	40.28	----	24.47	2,349	217	510,072	3,624,873	5,965,481	1.65	188

1/ Data on 13 general repair shops that could not be assigned to any single underground mine.

TABLE 28. - Injury experience, employment, and production data on bituminous-coal mines in the United States by number of shifts, 1965

Number of shifts	Number of injuries		Frequency rates				Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour	Number of mines
			Per million man-hours		Per million tons								
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal							
Underground mines (includes surface works):													
1 ----------------------	72	2,015	1.48	41.42	1.25	34.97	37,830	163	6,168,094	48,651,184	57,613,736	1.18	5,457
2 ----------------------	81	3,771	1.17	54.33	.61	28.56	38,708	225	8,724,894	69,415,170	132,045,200	1.90	550
3 ----------------------	76	3,097	1.11	45.29	.54	22.18	35,874	240	8,600,181	68,377,193	139,599,453	2.04	202
Combination -------------	3	77	1.30	33.34	.88	22.56	1,239	237	293,278	2,309,458	3,412,445	1.48	20
Total or average ------	232	8,960	1.23	47.47	.70	26.93	113,651	209	23,786,447	188,753,005	332,670,834	1.76	6,229
Strip mines:													
1 ----------------------	8	376	.46	21.83	.13	5.98	10,365	207	2,143,940	17,222,372	62,833,167	3.65	1,157
2 ----------------------	6	276	.56	25.59	.13	6.10	5,279	252	1,328,795	10,783,780	45,282,835	4.20	249
3 ----------------------	4	359	.32	28.59	.07	6.47	5,809	273	1,585,665	12,556,543	55,520,196	4.42	155
Combination -------------	---	21	-----	22.89	----	8.43	412	264	108,956	917,495	2,491,301	2.72	21
Total or average ------	18	1,032	.43	24.88	.11	6.21	21,865	236	5,167,356	41,480,190	166,127,499	4.00	1,582
Auger mines:													
1 ----------------------	---	62	-----	31.33	----	5.40	1,790	133	238,385	1,978,786	11,488,073	5.81	366
2 ----------------------	---	9	-----	29.35	----	4.06	248	154	38,296	306,661	2,216,230	7.23	27
3 ----------------------	1	8	10.60	84.77	1.72	13.77	48	239	11,451	94,378	581,068	6.16	4
Combination -------------	---	-----	-----	-----	----	-----	-------	---	----------	-----------	-----------	----	-----
Total or average ------	1	79	.42	33.20	.07	5.53	2,086	138	288,132	2,379,825	14,285,371	6.00	397

TABLE 29. - Injury experience, employment, and production data on Pennsylvania anthracite mines, by number of shifts, 1965

Number of shifts	Number of injuries		Frequency rates				Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour	Number of mines
			Per million man-hours		Per million tons								
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal							
Underground mines (includes surface works):													
1 ----------------------	5	115	1.54	35.48	2.19	50.29	2,522	188	475,319	3,241,501	2,286,845	0.71	598
2 ----------------------	1	293	.43	126.76	.58	171.20	1,515	211	319,028	2,311,448	1,711,447	.74	32
3 ----------------------	1	15	2.87	43.09	6.70	100.44	342	146	50,039	348,083	149,347	.43	4
Combination ------------	1	308	.43	133.41	.86	265.84	1,315	233	306,538	2,308,600	1,158,576	.50	3
Surface 1/ --------------	-	14	----	19.33	----	------	379	263	99,779	724,243	---------	----	---
Total or average-------	8	745	.90	83.39	1.51	140.40	6,073	206	1,250,703	8,933,875	5,306,215	.59	637
Strip mines:													
1 ----------------------	-	22	----	36.16	----	19.00	554	151	83,520	608,389	1,157,938	1.90	113
2 ----------------------	-	37	----	73.57	----	65.85	351	202	70,931	502,956	561,881	1.12	24
3 ----------------------	-	51	----	26.42	----	16.48	1,089	250	272,468	1,930,325	3,094,925	1.60	35
Combination ------------	-	36	----	61.73	----	31.28	355	234	83,153	583,203	1,150,737	1.97	16
Total or average ------	-	146	----	40.28	----	24.47	2,349	217	510,072	3,624,873	5,965,481	1.65	188

1/ Data on 13 general repair shops that could not be assigned to any single underground mine.

TABLE 30. - Injury experience, employment, and production data on bituminous-coal mines in the United States, by days-active group, 1965

Days-active group	Number of injuries		Frequency rates				Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour	Number of mines
			Per million man-hours		Per million tons								
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal							
Underground mines (includes surface works):													
1 to 49 --------------	9	79	8.64	75.87	6.47	56.83	4,460	29	131,076	1,041,312	1,390,017	1.33	755
50 to 99 --------------	16	258	3.46	55.87	2.29	36.90	7,812	74	579,099	4,618,211	6,991,729	1.51	961
100 to 149 --------------	13	305	1.79	41.89	1.27	29.90	7,481	122	912,189	7,281,660	10,202,078	1.40	1,025
150 to 199 --------------	16	663	1.18	48.73	.85	35.33	9,953	171	1,704,668	13,606,425	18,763,580	1.38	1,089
200 to 249 --------------	105	4,583	1.07	46.51	.58	25.24	53,389	233	12,452,132	98,538,082	181,567,828	1.84	1,881
250 to 299 --------------	73	3,030	1.16	48.21	.65	26.79	30,215	261	7,899,563	62,846,062	113,118,054	1.80	484
300 or more -------------	---	42	----	51.14	----	65.88	341	316	107,720	821,253	637,548	.78	34
Total or average ------	232	8,960	1.23	47.47	.70	26.93	113,651	209	23,786,447	188,753,005	332,670,834	1.76	6,229
Strip mines:													
1 to 49 --------------	---	7	----	33.98	----	9.29	864	30	25,526	206,030	753,743	3.66	168
50 to 99 --------------	---	23	----	25.80	----	7.54	1,471	73	107,611	891,471	3,048,427	3.42	211
100 to 149 --------------	---	41	----	28.80	----	7.68	1,406	124	173,755	1,423,471	5,340,193	3.75	191
150 to 199 --------------	3	77	1.16	29.81	.31	7.84	1,830	172	314,662	2,582,637	9,817,961	3.80	210
200 to 249 --------------	4	130	.66	21.32	.16	5.13	3,330	226	752,886	6,096,888	25,332,304	4.15	255
250 to 299 --------------	6	362	.37	22.49	.09	5.14	7,404	274	2,026,214	16,095,847	70,360,079	4.37	332
300 or more -------------	5	392	.35	27.64	.10	7.62	5,560	318	1,766,702	14,183,846	51,474,792	3.63	215
Total or average ------	18	1,032	.43	24.88	.11	6.21	21,865	236	5,167,356	41,480,190	166,127,499	4.00	1,582

TABLE 30. - Injury experience, employment, and production data on bituminous-coal mines in the United States, by days-active group, 1965--Continued

Days-active group	Number of injuries		Frequency rates				Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour	Number of mines
			Per million man-hours		Per million tons								
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal							
Auger mines:													
1 to 49 --------------	---	1	----	13.66	----	1.81	316	27	8,665	73,214	553,471	7.56	71
50 to 99 --------------	---	9	----	39.73	----	6.10	388	70	27,178	226,508	1,475,806	6.52	79
100 to 149 --------------	---	10	----	27.84	----	4.64	362	121	43,899	359,241	2,156,552	6.00	74
150 to 199 --------------	---	18	----	29.21	----	4.98	435	173	75,058	616,124	3,613,404	5.86	87
200 to 249 --------------	---	32	----	36.33	----	6.42	488	219	106,891	880,910	4,984,607	5.66	69
250 to 299 --------------	1	8	5.20	41.59	0.72	5.75	85	268	22,797	192,331	1,390,853	7.23	14
300 or more -------------	---	1	----	31.75	----	9.04	12	304	3,644	31,497	110,678	3.51	3
Total or average ------	1	79	.42	33.20	.07	5.53	2,086	138	288,132	2,379,825	14,285,371	6.00	379

TABLE 31. - Injury experience, employment, and production data on Pennsylvania anthracite mines, by days-active group, 1965

Days-active group	Number of injuries		Frequency rates				Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour	Number of mines
			Per million man-hours		Per million tons								
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal							
Underground mines (includes surface works):													
1 to 49 ---------------	1	3	17.89	53.66	33.32	99.97	242	32	7,842	55,909	30,008	0.54	58
50 to 99 ---------------	1	4	4.89	19.54	11.53	46.13	398	75	29,722	204,692	86,713	.42	129
100 to 149 ---------------	-	47	-----	92.44	-----	189.97	517	128	66,337	508,443	247,406	.49	92
150 to 199 ---------------	1	39	1.27	49.34	2.23	86.91	677	169	114,121	790,500	448,716	.57	71
200 to 249 ---------------	2	541	.41	112.09	.66	179.17	2,891	229	662,947	4,826,666	3,019,558	.63	137
250 to 299 ---------------	3	81	2.11	56.96	2.66	71.80	774	273	211,454	1,421,949	1,128,059	.79	120
300 or more --------------	-	16	-----	39.85	-----	46.28	195	300	58,501	401,473	345,755	.86	30
Surface 1/ ----------------	-	14	-----	19.33	-----	------	379	263	99,779	742,243	---------	----	---
Total or average -------	8	745	.90	83.39	1.51	140.40	6,073	206	1,250,703	8,933,875	5,306,215	.59	637
Strip mines:													
1 to 49 ---------------	-	3	-----	118.26	-----	35.73	134	25	3,340	25,367	83,967	3.31	29
50 to 99 ---------------	-	1	-----	13.09	-----	8.15	147	70	10,233	76,396	122,638	1.61	30
100 to 149 ---------------	-	3	-----	22.11	-----	12.10	151	126	19,035	135,694	248,015	1.83	26
150 to 199 ---------------	-	22	-----	41.30	-----	26.30	423	175	73,837	532,624	836,628	1.57	24
200 to 249 ---------------	-	45	-----	36.07	-----	18.72	761	234	177,977	1,247,588	2,404,157	1.93	47
250 to 299 ---------------	-	54	-----	75.42	-----	56.57	370	271	100,312	715,950	954,639	1.33	24
300 or more --------------	-	18	-----	20.20	-----	13.68	363	345	125,338	891,254	1,315,437	1.48	8
Total or average -------	-	146	-----	40.28	-----	24.47	2,349	217	510,072	3,624,873	5,965,481	1.65	188

1/ Data on 13 general repair shops that could not be assigned to any single underground mine.

TABLE 32. - Injury experience, employment, and production data on bituminous-coal mines (underground and surface works) in the United States, by thickness of bed or vein, 1965

Thickness of bed or vein, inches	Number of injuries		Frequency rates: Per million man-hours		Frequency rates: Per million tons		Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour	Number of mines
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal							
Less than 25 ---------------	1	14	1.36	18.98	2.21	30.88	588	159	93,277	737,551	453,389	0.61	110
25 to 36 -------------------	40	1,418	1.67	59.18	1.35	47.73	16,363	184	3,003,852	23,961,511	29,706,178	1.24	1,691
37 to 48 -------------------	55	2,642	1.20	57.71	.76	36.36	28,070	205	5,763,007	45,783,487	72,667,841	1.59	1,662
49 to 60 -------------------	50	1,684	1.48	49.73	.77	25.90	19,923	213	4,246,269	33,863,072	65,026,870	1.92	675
61 to 72 -------------------	27	1,188	1.05	45.98	.50	21.96	14,565	222	3,235,523	25,835,523	54,098,417	2.09	338
73 to 84 -------------------	33	780	1.58	37.40	.75	17.84	11,363	232	2,633,778	20,856,293	43,728,741	2.10	173
85 to 96 -------------------	10	474	.68	32.07	.33	15.80	8,107	231	1,875,210	14,781,859	29,997,747	2.03	95
97 to 108 ------------------	6	182	1.26	38.20	.42	12.69	2,390	250	596,797	4,764,162	14,344,231	3.01	26
109 or more ----------------	---	203	----	36.66	----	17.02	3,167	221	700,759	5,537,701	11,927,043	2.15	76
Not stated -----------------	8	304	1.16	43.95	.75	28.36	6,000	145	867,184	6,916,976	10,720,377	1.55	1,383
Surface 1/ -----------------	2	71	.35	12.42	----	-----	3,115	248	771,027	5,714,870	-----------	----	-----
Total or average ---------	232	8,960	1.23	47.47	.70	26.93	113,651	209	23,786,447	188,753,005	332,670,834	1.76	6,229

1/ Data on 73 surface installations (preparation plants and general repair shops) that could not be assigned to any single underground mine.

TABLE 33. - Injury experience, employment, and production data on Pennsylvania anthracite mines (underground and surface works), by thickness of bed or vein, 1965

Thickness of bed or vein, inches	Number of injuries		Frequency rates: Per million man-hours		Frequency rates: Per million tons		Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Ton per man-hour	Number of mines
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal							
Less than 25 ---------------	-	3	----	76.15	-----	188.85	35	154	5,380	39,398	15,886	0.40	10
25 to 36 -------------------	-	---	----	------	-----	------	224	116	26,029	175,439	83,985	.48	73
37 to 48 -------------------	-	48	----	68.00	-----	102.94	527	197	103,761	705,843	466,270	.66	104
49 to 60 -------------------	1	32	1.32	42.10	1.83	58.59	539	204	109,922	760,117	546,187	.72	113
61 to 72 -------------------	1	143	.76	108.19	.89	127.34	978	191	186,965	1,321,774	1,122,938	.85	72
73 to 84 -------------------	1	18	1.55	27.86	2.63	47.40	512	183	93,791	646,066	379,754	.59	44
85 to 96 -------------------	-	44	----	100.12	-----	116.27	288	227	65,470	439,456	378,444	.86	42
97 to 108 ------------------	-	22	----	81.57	-----	110.71	170	212	35,972	269,693	198,720	.74	20
109 or more ----------------	4	420	1.08	113.63	1.96	205.35	2,184	230	501,464	3,696,154	2,045,253	.55	72
Not stated -----------------	1	1	6.42	6.42	14.54	14.54	237	94	22,170	155,692	68,778	.44	87
Surface 1/ -----------------	-	14	----	19.33	-----	------	379	263	99,779	724,243	---------	----	---
Total or average ---------	8	745	.90	83.39	1.51	140.40	6,073	206	1,250,703	8,933,875	5,306,215	.59	637

1/ Data on 13 general repair shops that could not be assigned to any single underground mine.

TABLE 34. - Injury experience, employment, and production data on bituminous-coal mines in the United States, by production group, 1965

Production group, tons	Number of injuries		Frequency rates: Per million man-hours		Frequency rates: Per million tons		Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour	Number of mines
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal							
Underground mines (includes surface works):													
Less than 25,000 ----------	58	1,198	1.88	38.78	1.73	35.84	28,323	137	3,893,603	30,895,366	33,430,813	1.08	5,137
25,000 to 49,999 ----------	13	682	1.18	62.16	.86	44.87	7,230	190	1,374,627	10,972,064	15,199,766	1.39	421
50,000 to 99,999 ----------	15	587	1.79	69.86	1.04	40.51	5,177	203	1,052,254	8,402,453	14,489,278	1.72	209
100,000 to 249,999 --------	17	1,161	1.12	76.16	.62	42.12	9,092	211	1,916,236	15,244,519	27,561,366	1.81	174
250,000 to 499,999 --------	30	1,169	1.49	58.18	.85	33.23	10,769	234	2,525,279	20,091,290	35,175,804	1.75	98
500,000 to 749,999 --------	27	1,308	1.21	58.77	.61	29.60	11,850	236	2,794,677	22,254,441	44,185,814	1.99	72
750,000 to 999,999 --------	17	719	1.04	44.15	.52	22.13	8,349	247	2,058,423	16,287,056	32,490,380	1.99	38
1,000,000 or more ---------	53	2,065	.90	35.06	.41	15.87	29,746	249	7,400,321	58,890,946	130,137,613	2.21	80
Surface 1/ -----------------	2	71	.35	12.42	----	-----	3,115	248	771,027	5,714,870	-----------	----	-----
Total or average --------	232	8,960	1.23	47.47	.70	26.93	113,651	209	23,786,447	188,753,005	332,670,834	1.76	6,229
Strip mines:													
Less than 25,000 ----------	1	78	.25	19.41	.15	11.64	3,676	134	492,180	4,018,004	6,700,038	1.67	773
25,000 to 49,999 ----------	1	65	.26	16.64	.10	6.22	2,343	201	470,624	3,906,764	10,453,504	2.68	296
50,000 to 99,999 ----------	2	107	.37	19.56	.13	6.79	2,720	239	651,213	5,471,532	15,761,588	2.88	218
100,000 to 249,999 --------	3	156	.38	19.70	.12	6.33	3,706	255	943,253	7,918,267	24,647,065	3.11	168
250,000 to 499,999 --------	3	155	.65	33.38	.16	8.23	2,309	249	574,348	4,643,298	18,822,230	4.05	55
500,000 to 749,999 --------	---	64	----	28.02	----	5.41	1,133	261	296,208	2,284,458	11,839,171	5.18	20
750,000 to 999,999 --------	1	84	.35	29.61	.08	6.57	1,291	296	381,863	2,836,817	12,787,107	4.51	15
1,000,000 or more ---------	7	323	.67	31.05	.11	4.96	4,687	290	1,357,667	10,401,050	65,116,796	6.26	37
Total or average --------	18	1,032	.43	24.88	.11	6.21	21,865	236	5,167,356	41,480,190	166,127,499	4.00	1,582
Auger mines:													
Less than 25,000 ----------	---	28	----	39.92	----	9.22	936	91	84,764	701,394	3,038,055	4.33	250
25,000 to 49,999 ----------	---	8	----	20.04	----	3.37	358	138	49,464	399,241	2,374,028	5.95	63
50,000 to 99,999 ----------	---	15	----	24.92	----	3.92	368	193	71,016	601,839	3,831,318	6.37	54
100,000 to 249,999 --------	---	24	----	44.34	----	5.84	346	191	65,926	541,223	4,112,174	7.60	27
250,000 or more -----------	1	4	7.35	29.38	1.08	4.30	78	217	16,962	136,128	929,796	6.83	3
Total or average --------	1	79	.42	33.20	.07	5.53	2,086	138	288,132	2,379,825	14,285,371	6.00	397

1/ Data on 73 surface installations (preparation plants and general repair shops) that could not be assigned to any single underground mine.

TABLE 35. - Injury experience, employment, and production data on Pennsylvania anthracite mines, by production group, 1965

Production group, tons	Number of injuries		Frequency rates: Per million man-hours		Frequency rates: Per million tons		Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour	Number of mines
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal							
Underground mines (includes surface works):													
Less than 25,000 ----------	5	126	1.54	38.93	2.43	61.25	2,619	180	471,723	3,236,902	2,057,001	0.64	603
25,000 to 49,999 ----------	-	83	----	107.30	----	128.56	500	214	107,184	773,526	645,621	.83	20
50,000 to 99,999 ----------	1	66	1.76	116.48	2.35	154.84	355	227	80,658	566,613	426,253	.75	6
100,000 to 249,999 --------	1	48	1.45	69.57	2.52	121.07	500	190	95,031	689,962	396,481	.57	3
250,000 to 499,999 --------	1	256	.55	142.02	.78	200.81	1,071	229	245,134	1,802,501	1,274,864	.71	4
500,000 or more -----------	-	152	----	133.32	----	300.40	649	233	151,194	1,140,128	505,995	.44	1
Surface 1/ -----------------	-	14	----	19.33	----	------	379	263	99,779	724,243	---------	----	---
Total or average --------	8	745	.90	83.39	1.51	140.40	6,073	206	1,250,703	8,933,875	5,306,215	.59	637

TABLE 35. - Injury experience, employment, and production data on Pennsylvania anthracite mines, by production group, 1965--Continued

Production group, tons	Number of injuries		Frequency rates: Per million man-hours		Frequency rates: Per million tons		Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour	Number of mines
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal							
Strip mines:													
Less than 25,000 ----------	-	36	----	47.57	----	49.73	661	156	103,316	756,713	723,907	0.96	135
25,000 to 49,999 ----------	-	20	----	50.15	----	32.73	325	173	56,353	398,765	611,049	1.53	18
50,000 to 99,999 ----------	-	20	----	29.44	----	15.03	399	243	97,084	679,280	1,330,785	1.96	18
100,000 to 249,999 --------	-	47	----	48.20	----	29.40	557	248	138,288	975,157	1,598,446	1.64	12
250,000 or more -----------	-	23	----	28.22	----	13.52	407	283	115,031	814,958	1,701,294	2.09	5
Total or average --------	-	146	----	40.28	----	24.47	2,349	217	510,072	3,624,873	5,965,481	1.65	188
Culm banks:													
Less than 25,000 ----------	-	3	----	21.04	----	7.37	314	63	19,733	142,591	407,234	2.86	71
25,000 to 49,999 ----------	-	2	----	20.22	----	3.77	80	176	14,072	98,916	530,971	5.37	15
50,000 to 99,999 ----------	-	3	----	32.04	----	4.75	74	169	12,533	93,625	631,110	6.74	9
100,000 or more -----------	-	5	----	33.16	----	3.66	98	214	21,008	150,772	1,367,869	9.07	9
Total or average --------	-	13	----	26.75	----	4.43	566	119	67,346	485,904	2,937,184	6.04	104
Dredges --------------------	-	1	----	5.19	----	1.43	97	247	23,912	192,575	700,457	3.64	14
Preparation plants----------	-	162	----	51.62	----	-----	2,047	205	419,169	3,138,132	---------	----	---

1/ Data on 13 general repair shops that could not be assigned to any single underground mine.

TABLE 36. - Injury experience, employment, and production data on bituminous-coal mines (underground and surface works) in the United States, by kind of mine opening, 1965

Kind of opening	Number of injuries		Frequency rates: Per million man-hours		Frequency rates: Per million tons		Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Tons per man-hour	Number of mines
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal							
Shaft ----------------------	34	1,188	1.04	36.48	0.56	19.74	17,554	233	4,081,575	32,563,406	60,183,198	1.85	138
Slope ----------------------	47	2,003	1.21	51.61	.57	24.31	21,678	226	4,900,391	38,809,006	82,396,478	2.12	408
Drift ----------------------	145	5,392	1.38	51.44	.81	30.13	65,325	202	13,178,301	104,826,335	178,959,813	1.71	4,286
Not stated -----------------	4	306	.58	44.74	.36	27.49	5,979	143	855,153	6,839,388	11,131,345	1.63	1,397
Surface 1/ -----------------	2	71	.35	12.42	----	-----	3,115	248	771,027	5,714,870	-----------	----	-----
Total or average ----------	232	8,960	1.23	47.47	.70	26.93	113,651	209	23,786,447	188,753,005	332,670,834	1.76	6,229

1/ Data on 73 surface installations (preparation plants and general repair shops) that could not be assigned to any single underground mine.

TABLE 37. - Injury experience, employment, and production data on Pennsylvania anthracite mines (underground and surface works), by kind of mine opening, 1965

Kind of opening	Number of injuries		Frequency rates				Men at work	Days active	Man-days worked	Man-hours worked	Production, short tons	Ton per man-hour	Number of mines
			Per million man-hours		Per million tons								
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal							
Shaft ----------------	1	354	0.37	132.66	0.73	258.61	1,544	229	354,212	2,668,410	1,368,836	0.51	18
Slope ----------------	6	331	1.25	68.97	1.68	92.90	3,464	199	690,105	4,799,185	3,562,997	.74	507
Drift ----------------	1	46	1.64	75.45	3.20	147.38	482	182	87,871	609,690	312,116	.51	37
Not stated -----------	-	---	----	------	----	------	204	92	18,736	132,347	62,266	.47	75
Surface 1/ -----------	-	14	----	19.33	----	------	379	263	99,779	724,243	---------	----	---
Total or average ----	8	745	.90	83.39	1.51	140.40	6,073	206	1,250,703	8,933,875	5,306,215	.59	637

1/ Data on 13 general repair shops that could not be assigned to any single underground mine.

TABLE 38. - Relative standing of States according to fatal- and nonfatal-injury rates per million man-hours of exposure, 1965

State	Fatality rate	State	Nonfatal-injury rate
Indiana ----------	----	California ----------	-----
Missouri ----------	----	Oregon ----------	-----
Maryland ----------	----	Arizona ----------	-----
Wyoming ----------	----	South Dakota ----------	-----
Kansas ----------	----	Georgia ----------	-----
Iowa ----------	----	Texas ----------	13.28
Alaska ----------	----	Alabama ----------	13.54
Oklahoma ----------	----	Oklahoma ----------	17.20
Texas ----------	----	Maryland ----------	20.31
Arkansas ----------	----	Pennsylvania (bituminous) -	22.94
Washington ----------	----	Ohio ----------	24.85
Montana ----------	----	Kansas ----------	25.70
California ----------	----	Iowa ----------	27.94
Oregon ----------	----	New Mexico ----------	28.31
Arizona ----------	----	Tennessee ----------	29.41
South Dakota ----------	----	Wyoming ----------	29.60
Georgia ----------	----	Indiana ----------	32.19
Pennsylvania (anthracite) -	0.49	Utah ----------	36.45
Ohio ----------	.57	Missouri ----------	37.22
Alabama ----------	.73	Arkansas ----------	39.95
Pennsylvania (bituminous) -	.78	Colorado ----------	41.43
Utah ----------	.79	Illinois ----------	42.02
Illinois ----------	.86	North Dakota ----------	42.03
U. S. average (all coal)	1.04	U. S. average (bituminous)	43.30
U. S. average (bituminous)	1.08	U. S. average (all coal)	44.73
Kentucky ----------	1.15	Kentucky ----------	45.15
West Virginia ----------	1.25	Virginia ----------	53.48
Virginia ----------	1.40	West Virginia ----------	61.55
New Mexico ----------	1.89	Pennsylvania (anthracite) -	65.16
North Dakota ----------	2.00	Montana ----------	71.24
Tennessee ----------	3.00	Alaska ----------	80.05
Colorado ----------	4.18	Washington ----------	82.57

TABLE 39. - Employment and production data on coal mines in the United States, by State and general work location, 1965

State	Number of mines				Men at work						Days active	Man-days of work					
	Underground	Strip	Auger	Total	Underground mines			Strip mines	Auger mines	Total		Underground mines			Strip mines	Auger mines	Total
					Underground	Surface 1/	Total					Underground	Surface 1/	Total			
Alabama	130	53	5	188	3,938	848	4,786	811	35	5,632	212	829,092	177,228	1,006,320	183,432	6,670	1,196,422
Alaska	-----	6	---	6	------	------	-------	221	-----	221	251	----------	---------	----------	55,557	-------	55,557
Arizona	1	-----	---	1	4	------	4	------	-----	4	130	520	---------	520	---------	-------	520
Arkansas	6	10	---	16	49	11	60	63	-----	123	179	10,679	2,492	13,171	8,882	-------	22,053
California	-----	1	---	1	------	------	-------	4	-----	4	200	----------	---------	----------	800	-------	800
Colorado	82	9	---	91	1,138	271	1,409	127	-----	1,536	217	244,748	60,053	304,801	29,249	-------	334,050
Georgia	-----	-----	---	-----	------	------	-------	------	-----	------	---	----------	---------	----------	---------	-------	----------
Illinois	43	54	---	97	4,135	1,050	5,185	3,127	-----	8,312	252	950,796	276,864	1,227,660	868,310	-------	2,095,970
Indiana	18	35	---	53	778	322	1,100	1,470	-----	2,570	208	121,570	64,229	185,799	349,507	-------	535,306
Iowa	13	21	---	34	99	16	115	143	-----	258	213	16,331	3,085	19,416	35,538	-------	54,954
Kansas	-----	9	---	9	------	------	-------	235	-----	235	263	----------	---------	----------	61,857	-------	61,857
Kentucky	1,658	120	119	1,897	17,692	3,818	21,510	2,487	729	24,726	181	3,103,550	699,266	3,802,816	583,987	97,337	4,484,140
Maryland	57	33	2	92	232	40	272	141	4	417	191	41,430	8,257	49,687	29,699	360	79,746
Missouri	6	14	---	20	50	9	59	349	-----	408	266	6,764	1,426	8,190	100,176	-------	108,366
Montana	15	5	---	20	66	16	82	23	-----	105	152	10,095	2,631	12,726	3,195	-------	15,921
New Mexico	10	3	---	13	115	35	150	134	-----	284	233	21,895	8,132	30,027	36,015	-------	66,042
North Dakota	2	31	---	33	4	------	4	318	-----	322	196	274	---------	274	62,832	-------	63,106
Ohio	122	266	65	453	2,762	930	3,692	3,646	242	7,580	229	588,745	228,617	817,362	891,451	29,066	1,737,879
Oklahoma	8	18	1	27	25	4	29	229	3	261	197	1,917	438	2,355	49,070	38	51,463
Oregon	1	-----	---	1	3	3	6	------	-----	6	111	333	333	666	---------	-------	666
Pennsylvania (bituminous)	761	565	59	1,385	15,297	3,733	19,030	5,162	201	24,393	228	3,427,010	895,003	4,322,013	1,212,780	22,913	5,557,706
South Dakota	-----	1	---	1	------	------	-------	4	-----	4	125	----------	---------	----------	500	-------	500
Tennessee	234	51	8	293	1,737	292	2,029	416	58	2,503	181	309,943	58,675	368,618	78,525	7,040	454,183
Texas	-----	2	---	2	------	------	-------	102	-----	102	273	----------	---------	----------	27,890	-------	27,890
Utah	36	-----	---	36	1,070	425	1,495	------	-----	1,495	212	225,198	91,808	317,006	---------	-------	317,006
Virginia	1,471	59	55	1,585	9,300	1,387	10,687	358	150	11,195	201	1,853,943	293,929	2,147,872	74,559	25,568	2,247,999
Washington	6	2	---	8	64	17	81	2	-----	83	219	14,074	3,916	17,990	178	-------	18,168
West Virginia	1,542	204	83	1,829	33,358	8,419	41,777	2,054	664	44,495	215	7,269,457	1,846,637	9,116,094	364,267	99,140	9,579,501
Wyoming	7	10	---	17	66	23	89	239	-----	328	226	10,714	4,350	15,064	59,100	-------	74,164
Total or average, bituminous	6,229	1,582	397	8,208	91,982	21,669	113,651	21,865	2,086	137,602	213	19,059,078	4,727,369	23,786,447	5,167,356	288,132	29,241,935
Pennsylvania (anthracite) 2/	637	188	---	825	4,501	4,282	8,783	2,349	-----	11,132	204	907,491	853,639	1,761,130	510,072	-------	2,271,202
Grand total or average 2/	6,866	1,770	397	9,033	96,483	25,951	122,434	24,214	2,086	148,734	212	19,966,569	5,581,008	25,547,577	5,677,428	288,132	31,513,137

See footnotes at end of table.

TABLE 39. - Employment and production data on coal mines in the United States, by State and general work location, 1965--Continued

State	Man-hours of work						Production, short tons				Tons per man-hour			
	Underground mines			Strip mines	Auger mines	Total	Under-ground mines 1/	Strip mines	Auger mines	Total	Under-ground mines 1/	Strip mines	Auger mines	Total
	Under-ground	Surface 1/	Total											
Alabama	6,685,377	1,337,744	8,023,121	1,457,853	49,593	9,530,567	9,916,988	4,914,831	119,342	14,951,161	1.24	3.37	2.41	1.57
Alaska	-----	-----	-----	449,716	-----	449,716	-----	911,197	-----	911,197	----	2.03	----	2.03
Arizona	4,160	-----	4,160	-----	-----	4,160	(3/)	-----	-----	(3/)	(3/)	----	----	(3/)
Arkansas	85,432	19,391	104,823	70,388	-----	175,211	(3/)	(3/)	-----	(3/)	(3/)	(3/)	----	(3/)
California	-----	-----	-----	6,400	-----	6,400	-----	(3/)	-----	(3/)	----	(3/)	----	(3/)
Colorado	1,950,765	457,703	2,408,468	222,378	-----	2,630,846	3,523,685	1,393,939	-----	4,917,624	1.46	6.27	----	1.87
Georgia	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	----	----	----	----
Illinois	7,643,872	2,045,817	9,689,689	6,661,109	-----	16,350,798	25,749,600	32,610,760	-----	58,360,360	2.66	4.90	----	3.57
Indiana	973,256	479,875	1,453,131	2,647,641	-----	4,100,772	2,282,403	13,178,588	-----	15,460,991	1.57	4.98	----	3.77
Iowa	129,224	24,322	153,546	311,667	-----	465,213	197,440	865,590	-----	1,063,030	1.29	2.78	----	2.29
Kansas	-----	-----	-----	505,915	-----	505,915	-----	1,311,306	-----	1,311,306	----	2.59	----	2.59
Kentucky	24,859,352	5,393,721	30,253,073	4,574,721	811,995	35,639,789	50,715,649	30,091,329	4,917,952	85,724,930	1.68	6.58	6.06	2.41
Maryland	323,054	65,576	388,630	248,715	2,880	640,225	443,398	799,599	2,104	1,245,101	1.14	3.21	.73	1.94
Missouri	54,112	11,408	65,520	767,349	-----	832,869	26,774	3,520,037	-----	3,546,811	.41	4.59	----	4.26
Montana	80,222	20,643	100,865	25,475	-----	126,340	(3/)	(3/)	-----	(3/)	(3/)	(3/)	----	(3/)
New Mexico	180,523	67,012	247,535	282,297	-----	529,832	420,007	2,781,175	-----	3,201,182	1.70	9.85	----	6.04
North Dakota	2,192	-----	2,192	497,396	-----	499,588	2,246	2,753,463	-----	2,755,709	1.02	5.54	----	5.52
Ohio	4,704,853	1,707,645	6,412,498	7,296,454	254,483	13,963,435	11,120,376	26,686,305	1,828,583	39,635,264	1.73	3.66	7.19	2.84
Oklahoma	15,336	3,504	18,840	387,902	304	407,046	9,476	995,812	1,119	1,006,407	.50	2.57	3.68	2.47
Oregon	2,664	2,664	5,328	-----	-----	5,328	(3/)	-----	-----	(3/)	(3/)	----	----	(3/)
Pennsylvania (bituminous)	27,618,114	6,706,472	34,324,586	10,170,365	195,539	44,690,490	55,813,197	23,670,557	799,525	80,283,279	1.63	2.33	4.09	1.80
South Dakota	-----	-----	-----	4,000	-----	4,000	-----	(3/)	-----	(3/)	----	(3/)	----	(3/)
Tennessee	2,514,256	466,133	2,980,389	635,657	56,326	3,672,372	3,414,139	2,136,039	205,830	5,756,008	1.15	3.36	3.65	1.57
Texas	-----	-----	-----	225,948	-----	225,948	-----	(3/)	-----	(3/)	----	(3/)	----	(3/)
Utah	1,830,990	693,065	2,524,055	-----	-----	2,524,055	5,010,150	-----	-----	5,010,150	1.98	----	----	1.98
Virginia	14,829,146	2,267,065	17,096,211	611,965	205,598	17,913,774	29,401,827	3,026,246	1,634,231	34,062,304	1.72	4.95	7.95	1.90
Washington	112,572	31,328	143,900	1,424	-----	145,324	(3/)	(3/)	-----	(3/)	(3/)	(3/)	----	(3/)
West Virginia	58,336,586	13,898,200	72,234,786	2,960,834	803,107	75,998,727	134,291,900	10,611,752	4,776,685	149,680,337	1.86	3.58	5.95	1.97
Wyoming	85,227	32,432	117,659	456,621	-----	574,280	124,652	3,149,930	-----	3,274,582	1.06	6.90	----	5.70
All other	-----	-----	-----	-----	-----	-----	206,927	719,044	-----	925,971	----	----	----	----
Total or average, bituminous	153,021,285	35,731,720	188,753,005	41,480,190	2,379,825	232,613,020	332,670,834	166,127,499	14,285,371	513,083,704	1.76	4.00	6.00	2.21
Pennsylvania (anthracite)	6,443,993	6,306,493	12,750,486	3,624,873	-----	16,375,359	8,943,856	5,965,481	-----	14,909,337	.70	1.65	----	.91
Grand total or average	159,465,278	42,038,213	201,503,491	45,105,063	2,379,825	248,988,379	341,614,690	172,092,980	14,285,371	527,993,041	1.70	3.82	6.00	2.12

1/ Includes culm banks, dredges, preparation plants, and general repair shops at Pennsylvania anthracite mines.
2/ Number of mines does not include 104 culm banks, 14 dredges, 146 preparation plants, and 13 general repair shops.
3/ Production included in "all other."

TABLE 40. - Number of fatal injuries at coal mines in the United States, by State, general work location, and principal causes of injury, 1965

State	Underground																		
	Falls of roof	Falls of face	Inrush of water and materials	Pressure bumps or bursts	Other falling materials or objects	Slips or falls of persons	Handling materials	Handtools	Stepping or kneeling on sharp or loose objects	Striking or bumping against objects	Haulage	Explosions of gas or coal dust	Explosives	Electricity	Machinery	Suffocation	Mine fires	All other	Total underground
Alabama	4	--	-	-	-	-	-	-	-	-	1	--	-	-	--	-	1	-	6
Alaska	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
Arizona	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
Arkansas	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
California	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
Colorado	---	--	-	-	-	-	-	-	-	-	2	9	-	-	--	-	--	-	11
Georgia	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
Illinois	4	--	-	-	-	-	-	-	-	-	1	--	-	-	1	-	--	-	6
Indiana	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
Iowa	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
Kansas	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
Kentucky	25	--	-	1	-	-	-	-	-	-	5	--	-	1	3	-	--	-	35
Maryland	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
Missouri	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
Montana	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
New Mexico	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
North Dakota	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
Ohio	2	--	-	-	-	-	-	-	-	-	1	--	1	-	--	-	--	-	4
Oklahoma	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
Oregon	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
Pennsylvania (bituminous)	16	--	-	-	-	-	-	-	-	-	8	--	-	-	3	-	1	-	28
South Dakota	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
Tennessee	5	--	-	-	-	-	-	-	-	-	1	5	-	-	--	-	--	-	11
Texas	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
Utah	1	--	-	-	-	-	-	-	-	-	--	--	-	1	--	-	--	-	2
Virginia	16	1	-	-	-	-	-	-	-	-	4	--	-	1	2	-	--	-	24
Washington	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
West Virginia	46	6	-	1	1	-	-	-	-	-	11	1	-	1	5	-	9	-	81
Wyoming	---	--	-	-	-	-	-	-	-	-	--	--	-	-	--	-	--	-	---
Total, bituminous	119	7	-	2	1	-	-	-	-	-	34	15	1	4	14	-	11	-	208
Pennsylvania (anthracite)	2	3	2	-	-	-	-	-	-	-	1	--	-	-	--	-	--	-	8
All coal	121	10	2	2	1	-	-	-	-	-	35	15	1	4	14	-	11	-	216

TABLE 40. - Number of fatal injuries at coal mines in the United States, by State, general work location, and principal causes of injury, 1965--Continued

State	Shaft and Slope																		
	Falls of roof	Falls of face	Pressure bumps or bursts	Other falling materials or objects	Slips or falls of persons	Handling materials	Handtools	Stepping or kneeling on sharp or loose objects	Striking or bumping against objects	Haulage	Explosions of gas or coal dust	Explosives	Electricity	Machinery	Suffocation	Mine fires	All other	Total shaft and slope	Total underground (including shaft and slope)
Alabama	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
Alaska	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Arizona	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Arkansas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
California	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Colorado	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
Georgia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Illinois	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	7
Indiana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Iowa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Kansas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Kentucky	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	35
Maryland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Missouri	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Montana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
New Mexico	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
North Dakota	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Ohio	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
Oklahoma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Oregon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Pennsylvania (bituminous)	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	2	30
South Dakota	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Tennessee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
Texas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Utah	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Virginia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24
Washington	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
West Virginia	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	4	85
Wyoming	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Total, bituminous	-	-	-	2	1	-	-	-	-	-	4	-	-	-	-	-	-	7	215
Pennsylvania (anthracite)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
All coal	-	-	-	2	1	-	-	-	-	-	4	-	-	-	-	-	-	7	223

TABLE 40. - Number of fatal injuries at coal mines in the United States, by State, general work location, and principal causes of injury, 1965--Continued

State	Surface															
	Falls or slides of coal or overburden	Other falling materials or objects	Slips or falls of persons	Handling materials	Handtools	Stepping or kneeling on sharp or loose objects	Striking or bumping against objects	Haulage	Explosions of gas or coal dust	Explosives	Electricity	Machinery	Suffocation	Fires	All other	Total surface
Alabama	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Alaska	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Arizona	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Arkansas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
California	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Colorado	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Georgia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Illinois	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1
Indiana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Iowa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Kansas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Kentucky	-	-	-	-	-	-	-	2	-	-	-	1	-	-	1	4
Maryland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Missouri	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Montana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
New Mexico	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
North Dakota	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Ohio	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1
Oklahoma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Oregon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Pennsylvania (bituminous)	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1
South Dakota	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Tennessee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Texas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Utah	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Virginia	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1
Washington	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
West Virginia	-	1	1	-	-	-	-	3	-	-	1	3	-	-	-	9
Wyoming	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Total, bituminous	-	1	1	-	-	-	-	7	-	-	2	5	-	-	1	17
Pennsylvania (anthracite) 1/	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
All coal 1/	-	1	1	-	-	-	-	7	-	-	2	5	-	-	1	17

See footnote at end of table.

TABLE 40. - Number of fatal injuries at coal mines in the United States, by State, general work location, and principal causes of injury, 1965--Continued

State	Strip															
	Falls or slides of coal or overburden	Other falling materials or objects	Slips or falls of persons	Handling materials	Handtools	Stepping or kneeling on sharp or loose objects	Striking or bumping against objects	Haulage	Explosions of gas or coal dust	Explosives	Electricity	Machinery	Suffocation	Fires	All other	Total strip
Alabama	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1
Alaska	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Arizona	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Arkansas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
California	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Colorado	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Georgia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Illinois	1	-	1	-	-	-	-	-	-	-	1	2	-	-	1	6
Indiana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Iowa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Kansas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Kentucky	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	2
Maryland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Missouri	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Montana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
New Mexico	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1
North Dakota	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1
Ohio	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-	3
Oklahoma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Oregon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Pennsylvania (bituminous)	1	1	-	-	-	-	-	-	-	-	-	2	-	-	-	4
South Dakota	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Tennessee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Texas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Utah	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Virginia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Washington	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
West Virginia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Wyoming	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
Total, bituminous	2	1	2	-	-	-	-	-	-	1	3	8	-	-	1	18
Pennsylvania (anthracite)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
All coal	2	1	2	-	-	-	-	-	-	1	3	8	-	-	1	18

TABLE 40. - Number of fatal injuries at coal mines in the United States, by State, general work location, and principal causes of injury, 1965--Continued

State	Auger																Culm banks	Dredges	Preparation plants	Total, all mines
	Falls or slides of coal or overburden	Other falling materials or objects	Slips or falls of persons	Handling materials	Handtools	Stepping or kneeling on sharp or loose objects	Striking or bumping against objects	Haulage	Explosions of gas or coal dust	Explosives	Electricity	Machinery	Suffocation	Fires	All other	Total auger				
Alabama	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
Alaska	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Arizona	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Arkansas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
California	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Colorado	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
Georgia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Illinois	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14
Indiana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Iowa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Kansas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Kentucky	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	41
Maryland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Missouri	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Montana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
New Mexico	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
North Dakota	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Ohio	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
Oklahoma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Oregon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Pennsylvania (bituminous)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	35
South Dakota	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Tennessee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
Texas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Utah	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Virginia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25
Washington	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
West Virginia	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	95
Wyoming	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	---
Total, bituminous	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	251
Pennsylvania (anthracite)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
All coal	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	259

1/ Includes shops and yards at Pennsylvania anthracite mines.

TABLE 41. - Number of nonfatal injuries at coal mines in the United States, by State, general work location, and principal causes of injury, 1965

State	Underground																		
	Falls of roof	Falls of face	Pressure bumps or bursts	Other falling materials or objects	Slips or falls of persons	Handling materials	Handtools	Stepping or kneeling on sharp or loose objects	Striking or bumping against objects	Haulage	Explosions of gas or coal dust	Explosives	Electricity	Machinery	Suffocation	Mine fires	All other	Occupational diseases	Total underground
Alabama	23	7	--	1	5	14	1	1	--	22	1	--	---	16	-	--	---	-	91
Alaska	-----	---	--	---	---	-----	---	---	--	-----	--	--	---	-----	-	--	---	-	-----
Arizona	-----	---	--	---	---	-----	---	---	--	-----	--	--	---	-----	-	--	---	-	-----
Arkansas	-----	---	--	---	---	4	---	---	--	1	--	--	---	2	-	--	---	-	7
California	-----	---	--	---	---	-----	---	---	--	-----	--	--	---	-----	-	--	---	-	-----
Colorado	12	7	2	3	13	30	2	---	--	12	--	--	1	10	-	--	2	-	94
Georgia	-----	---	--	---	---	-----	---	---	--	-----	--	--	---	-----	-	--	---	-	-----
Illinois	95	25	--	8	33	77	15	10	5	59	--	25	17	96	-	1	4	-	470
Indiana	6	1	--	5	7	7	1	1	--	6	--	--	1	10	-	--	---	-	45
Iowa	3	---	--	---	---	2	---	---	--	1	--	--	1	2	-	--	---	-	9
Kansas	-----	---	--	---	---	-----	---	---	--	-----	--	--	---	-----	-	--	---	-	-----
Kentucky	210	35	1	16	45	325	49	29	10	257	4	16	51	186	-	6	13	-	1,253
Maryland	4	---	--	---	---	1	---	---	--	2	--	--	---	1	-	--	---	-	8
Missouri	-----	---	--	---	---	-----	---	---	--	-----	--	--	---	-----	-	--	---	-	-----
Montana	-----	---	--	---	1	1	1	---	--	1	--	--	---	2	-	--	1	-	7
New Mexico	4	---	--	---	1	4	---	---	--	1	--	--	1	-----	-	--	---	-	11
North Dakota	-----	---	--	---	---	-----	---	---	--	-----	--	--	---	-----	-	--	---	-	-----
Ohio	34	3	--	9	14	40	9	4	1	45	--	2	9	29	-	--	4	-	203
Oklahoma	-----	---	--	---	---	-----	---	---	--	-----	--	--	---	-----	-	--	---	-	-----
Oregon	-----	---	--	---	---	-----	---	---	--	-----	--	--	---	-----	-	--	---	-	-----
Pennsylvania (bituminous)	123	20	--	10	40	142	30	21	3	144	5	6	13	140	-	2	8	1	708
South Dakota	-----	---	--	---	---	-----	---	---	--	-----	--	--	---	-----	-	--	---	-	-----
Tennessee	16	3	--	---	3	22	3	2	--	21	--	3	2	16	-	3	---	-	94
Texas	-----	---	--	---	---	-----	---	---	--	-----	--	--	---	-----	-	--	---	-	-----
Utah	10	7	3	1	6	20	---	1	2	14	2	1	1	10	-	--	---	-	78
Virginia	165	23	--	6	29	196	32	25	3	196	2	5	19	135	1	2	10	-	849
Washington	1	---	--	1	2	4	---	---	--	1	--	--	---	1	-	--	---	-	10
West Virginia	661	130	6	71	114	900	142	75	17	825	1	31	186	730	3	16	58	-	3,966
Wyoming	2	---	--	---	---	1	---	---	--	4	--	--	2	1	-	--	---	-	10
Total bituminous	1,369	261	12	131	313	1,790	285	169	41	1,612	15	89	304	1,387	4	30	100	1	7,913
Pennsylvania (anthracite)	21	67	7	68	133	147	49	27	2	75	5	6	6	78	-	--	3	-	694
All coal	1,390	328	19	199	446	1,937	334	196	43	1,687	20	95	310	1,465	4	30	103	1	8,607

TABLE 41. - Number of nonfatal injuries at coal mines in the United States, by State, general work location, and principal causes of injury, 1965--Continued

State	Shaft and Slope																		
	Falls of roof	Falls of face	Pressure bumps or bursts	Other falling materials or objects	Slips or falls of persons	Handling materials	Handtools	Stepping or kneeling on sharp or loose objects	Striking or bumping against objects	Haulage	Explosions of gas or coal dust	Explosives	Electricity	Machinery	Suffocation	Mine fires	All other	Total shaft and slope	Total underground (including shaft and slope)
Alabama	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	91
Alaska	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	-----
Arizona	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	-----
Arkansas	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	7
California	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	-----
Colorado	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	95
Georgia	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	-----
Illinois	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	2	472
Indiana	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	45
Iowa	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	9
Kansas	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	-----
Kentucky	-	-	-	-	9	1	1	1	-	-	-	-	-	1	-	-	1	14	1,267
Maryland	-	-	-	-	--	-	1	-	-	-	-	-	-	-	-	-	-	1	9
Missouri	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	-----
Montana	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	7
New Mexico	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	11
North Dakota	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	-----
Ohio	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	204
Oklahoma	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	-----
Oregon	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	-----
Pennsylvania (bituminous)	-	-	-	-	--	1	-	-	-	-	-	-	-	-	-	-	-	1	709
South Dakota	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	-----
Tennessee	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	94
Texas	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	-----
Utah	-	-	-	-	--	-	-	-	-	1	-	-	-	-	-	-	-	1	79
Virginia	1	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	3	852
Washington	-	-	-	-	--	-	-	-	-	-	-	-	-	-	-	-	-	--	10
West Virginia	1	1	-	-	3	5	1	-	-	1	-	-	-	-	-	-	-	12	3,978
Wyoming	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	2	12
Total bituminous	2	1	-	-	18	7	3	1	-	4	-	-	-	1	-	-	1	38	7,951
Pennsylvania (anthracite)	1	-	-	-	--	-	-	3	-	2	-	-	-	-	-	-	-	6	700
All coal	3	1	-	-	18	7	3	4	-	6	-	-	-	1	-	-	1	44	8,651

TABLE 41. - Number of nonfatal injuries at coal mines in the United States, by State, general work location, and principal causes of injury, 1965--Continued

State	Surface																
	Falls of coal or overburden	Falling materials or objects	Slips or falls of persons	Handling materials	Handtools	Stepping or kneeling on sharp or loose objects	Striking or bumping against objects	Haulage	Explosions of gas or coal dust	Explosives	Electricity	Machinery	Suffocation	Fires	All other	Occupational diseases	Total surface
Alabama	-	--	4	7	1	--	-	2	-	-	--	--	-	-	--	-	14
Alaska	-	--	---	---	--	--	-	---	-	-	--	--	-	-	--	-	-----
Arizona	-	--	---	---	--	--	-	---	-	-	--	--	-	-	--	-	-----
Arkansas	-	--	---	---	--	--	-	---	-	-	--	--	-	-	--	-	-----
California	-	--	---	---	--	--	-	---	-	-	--	--	-	-	--	-	-----
Colorado	-	--	3	4	--	--	-	1	-	-	--	--	-	-	--	-	8
Georgia	-	--	---	---	--	--	-	---	-	-	--	--	-	-	--	-	-----
Illinois	-	--	7	10	3	--	-	8	-	-	--	3	-	1	2	-	34
Indiana	-	--	1	3	1	1	-	3	-	-	1	2	-	-	1	-	13
Iowa	-	--	1	---	--	--	-	---	-	-	--	--	-	-	--	-	1
Kansas	-	--	---	---	--	--	-	---	-	-	--	--	-	-	--	-	-----
Kentucky	-	2	12	57	11	4	-	44	-	-	2	7	-	2	4	-	145
Maryland	-	--	---	1	--	--	-	2	-	-	--	--	-	-	--	-	3
Missouri	-	--	---	---	--	--	-	---	-	-	--	--	-	-	--	-	-----
Montana	-	--	1	---	--	--	-	---	-	-	--	1	-	-	--	-	2
New Mexico	-	--	1	1	--	--	-	1	-	-	--	--	-	-	--	-	3
North Dakota	-	--	---	---	--	--	-	---	-	-	--	--	-	-	--	-	-----
Ohio	-	--	9	2	1	3	-	8	-	-	--	4	-	1	1	-	29
Oklahoma	-	--	---	---	--	--	-	---	-	-	--	--	-	-	--	-	-----
Oregon	-	--	---	---	--	--	-	---	-	-	--	--	-	-	--	-	-----
Pennsylvania (bituminous)	-	--	13	29	2	3	-	24	1	-	1	17	-	-	3	-	93
South Dakota	-	--	---	---	--	--	-	---	-	-	--	--	-	-	--	-	-----
Tennessee	-	--	---	1	1	--	-	2	-	-	1	1	-	-	--	-	6
Texas	-	--	---	---	--	--	-	---	-	-	--	--	-	-	--	-	-----
Utah	-	1	1	2	1	1	-	4	1	-	--	1	-	-	1	-	13
Virginia	-	1	7	23	7	1	-	32	-	-	2	3	-	-	5	1	82
Washington	-	--	1	1	--	--	-	---	-	-	--	--	-	-	--	-	2
West Virginia	3	12	72	179	28	14	-	156	3	1	15	49	-	4	23	-	559
Wyoming	-	1	---	1	--	--	-	---	-	-	--	--	-	-	--	-	2
Total bituminous	3	17	133	321	56	27	-	287	5	1	22	88	-	8	40	1	1,009
Pennsylvania (anthracite) 1/	-	--	6	15	4	--	-	10	-	-	1	7	-	-	2	-	45
All coal 1/	3	17	139	336	60	27	-	297	5	1	23	95	-	8	42	1	1,054

See footnote at end of table.

TABLE 41. - Number of nonfatal injuries at coal mines in the United States, by State, general work location, and principal causes of injury, 1965--Continued

State	Strip															
	Falls of coal or overburden	Other falling materials or objects	Slips or falls of persons	Handling materials	Handtools	Stepping or kneeling on sharp or loose objects	Striking or bumping against objects	Haulage	Explosions of gas or coal dust	Explosives	Electricity	Machinery	Suffocation	Fires	All other	Total strip
Alabama	--	--	3	5	1	--	-	5	-	--	-	8	-	-	--	22
Alaska	--	1	5	9	2	--	-	10	-	--	-	4	-	-	5	36
Arizona	--	--	---	---	--	--	-	---	-	--	-	---	-	-	--	-----
Arkansas	--	--	---	---	--	--	-	---	-	--	-	---	-	-	--	-----
California	--	--	---	---	--	--	-	---	-	--	-	---	-	-	--	-----
Colorado	--	--	---	1	2	--	-	---	-	--	-	2	-	-	1	6
Georgia	--	--	---	---	--	--	-	---	-	--	-	---	-	-	--	-----
Illinois	4	4	34	56	12	4	-	32	-	2	2	20	-	1	10	181
Indiana	6	--	6	19	2	1	1	16	-	--	1	18	-	1	3	74
Iowa	--	--	---	1	--	--	-	---	-	--	-	1	-	-	1	3
Kansas	--	--	3	3	2	--	-	3	-	--	-	---	-	-	2	13
Kentucky	5	4	20	53	17	7	-	28	-	4	2	25	-	1	11	177
Maryland	--	--	1	---	--	--	-	---	-	--	-	---	-	-	--	1
Missouri	--	1	4	10	2	1	-	1	-	1	-	5	-	-	6	31
Montana	--	--	---	---	--	--	-	---	-	--	-	---	-	-	--	-----
New Mexico	--	--	---	1	--	--	-	---	-	--	-	---	-	-	--	1
North Dakota	--	--	4	7	2	1	-	4	-	--	-	1	-	-	2	21
Ohio	3	2	20	33	4	2	-	14	-	3	1	23	-	1	3	109
Oklahoma	--	--	1	1	1	--	-	1	-	--	-	1	-	-	2	7
Oregon	--	--	---	---	--	--	-	---	-	--	-	---	-	-	--	-----
Pennsylvania (bituminous)	3	--	49	63	6	5	-	23	-	--	1	51	-	1	16	218
South Dakota	--	--	---	---	--	--	-	---	-	--	-	---	-	-	--	-----
Tennessee	--	--	1	2	2	--	-	1	-	--	-	2	-	-	--	8
Texas	--	--	2	1	--	--	-	---	-	--	-	---	-	-	--	3
Utah	--	--	---	---	--	--	-	---	-	--	-	---	-	-	--	-----
Virginia	1	1	6	2	--	--	-	4	-	--	-	3	-	-	2	19
Washington	--	--	---	---	--	--	-	---	-	--	-	---	-	-	--	-----
West Virginia	3	2	16	28	6	3	-	11	-	--	1	24	-	2	3	99
Wyoming	--	--	---	---	--	--	-	1	-	--	-	2	-	-	--	3
Total bituminous	25	15	175	295	61	24	1	154	-	10	8	190	-	7	67	1,032
Pennsylvania (anthracite)	1	7	32	29	8	2	-	25	-	3	-	28	-	-	11	146
All coal	26	22	207	324	69	26	1	179	-	13	8	218	-	7	78	1,178

TABLE 41. - Number of nonfatal injuries at coal mines in the United States, by State, general work location, and principal causes of injury, 1965--Continued

State	Auger																Culm banks	Dredges	Preparation plants	Total, all mines
	Falls of coal or overburden	Other falling materials or objects	Slips or falls of persons	Handling materials	Handtools	Stepping or kneeling on sharp or loose objects	Striking or bumping against objects	Haulage	Explosions of gas or coal dust	Explosives	Electricity	Machinery	Suffocation	Fires	All other	Total auger				
Alabama	-	-	-	--	-	1	-	-	-	-	-	1	-	-	-	2	--	-	---	129
Alaska	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	36
Arizona	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	------
Arkansas	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	7
California	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	------
Colorado	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	109
Georgia	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	------
Illinois	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	687
Indiana	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	132
Iowa	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	13
Kansas	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	13
Kentucky	1	-	2	8	1	-	-	1	-	-	-	7	-	-	-	20	--	-	---	1,609
Maryland	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	13
Missouri	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	31
Montana	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	9
New Mexico	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	15
North Dakota	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	21
Ohio	-	-	-	2	-	-	-	-	-	-	-	3	-	-	-	5	--	-	---	347
Oklahoma	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	7
Oregon	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	------
Pennsylvania (bituminous)	-	-	-	3	-	-	-	-	-	-	-	2	-	-	-	5	--	-	---	1,025
South Dakota	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	------
Tennessee	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	108
Texas	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	3
Utah	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	92
Virginia	-	-	-	2	-	-	-	-	-	-	-	3	-	-	-	5	--	-	---	958
Washington	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	12
West Virginia	-	1	4	10	3	-	-	3	-	-	-	17	-	-	4	42	--	-	---	4,678
Wyoming	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	--	-	---	17
Total bituminous	1	1	6	25	4	1	-	4	-	-	-	33	-	-	4	79	--	-	---	10,071
Pennsylvania (anthracite)	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	--	13	1	162	1,067
All coal	1	1	6	25	4	1	-	4	-	-	-	33	-	-	4	79	13	1	162	11,138

1/ Includes shops and yards at Pennsylvania anthracite mines.

TABLE 42. - Number of injuries, by percentage distribution, average severity, and injury rates at coal mines in the United States, by State and degree of injury, 1965

State	Number of injuries						Distribution of all injuries, percent	Average severity			Severity rates				Frequency rates			
	Fatal	Nonfatal				All injuries		Permanent partial	Temporary total	All injuries	Per million man-hours		Per million tons		Per million man-hours		Per million tons	
		Permanent		Temporary total	Total nonfatal													
		Total	Partial								Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal
Underground mines:																		
Underground (including shaft and slope):																		
Alabama	6	--	7	84	91	97	1.2	126	70	441	5,385	1,007	3,630	679	0.90	13.61	0.61	9.18
Alaska	---	--	---	-----	-----	-----	----	-----	--	---	------	------	------	------	----	------	----	------
Arizona	---	--	---	-----	-----	-----	----	-----	--	---	------	------	------	------	----	------	----	------
Arkansas	---	--	---	7	7	7	.1	-----	19	19	------	1,568	------	(1/)	----	81.94	----	(1/)
California	---	--	---	-----	-----	-----	----	-----	--	---	------	------	------	------	----	------	----	------
Colorado	11	--	1	94	95	106	1.3	120	29	649	33,833	1,448	18,730	801	5.64	48.70	3.12	26.96
Georgia	---	--	---	-----	-----	-----	----	-----	--	---	------	------	------	------	----	------	----	------
Illinois	7	--	10	462	472	479	5.9	1,208	38	150	5,495	3,900	1,631	1,158	.92	61.75	.27	18.33
Indiana	---	--	1	44	45	45	.6	4,500	42	141	------	6,508	------	2,775	----	46.24	----	19.72
Iowa	---	--	1	8	9	9	.1	60	24	28	------	1,950	------	1,276	----	69.65	----	45.58
Kansas	---	--	---	-----	-----	-----	----	-----	--	---	------	------	------	------	----	------	----	------
Kentucky	35	2	26	1,239	1,267	1,302	15.9	701	33	216	8,448	2,878	4,141	1,411	1.41	50.97	.69	24.98
Maryland	---	1	---	8	9	9	.1	-----	52	713	------	19,851	------	14,463	----	27.86	----	20.30
Missouri	---	--	---	-----	-----	-----	----	-----	--	---	------	------	------	------	----	------	----	------
Montana	---	--	---	7	7	7	.1	-----	25	25	------	2,169	------	(1/)	----	87.26	----	(1/)
New Mexico	---	--	---	11	11	11	.1	-----	41	41	------	2,520	------	1,083	----	60.93	----	26.19
North Dakota	---	--	---	-----	-----	-----	----	-----	--	---	------	------	------	------	----	------	----	------
Ohio	4	--	3	201	204	208	2.5	1,578	39	175	5,101	2,654	2,158	1,123	.85	43.36	.36	18.34
Oklahoma	---	--	---	-----	-----	-----	----	-----	--	---	------	------	------	------	----	------	----	------
Oregon	---	--	---	-----	-----	-----	----	-----	--	---	------	------	------	------	----	------	----	------
Pennsylvania (bituminous)	30	1	28	680	709	739	9.0	406	55	318	6,517	1,985	3,225	982	1.09	25.67	.54	12.70
South Dakota	---	--	---	-----	-----	-----	----	-----	--	---	------	------	------	------	----	------	----	------
Tennessee	11	--	1	93	94	105	1.3	135	29	655	26,250	1,115	19,331	821	4.38	37.39	3.22	27.53
Texas	---	--	---	-----	-----	-----	----	-----	--	---	------	------	------	------	----	------	----	------
Utah	2	1	3	75	79	81	1.0	173	28	255	6,554	4,705	2,395	1,720	1.09	43.15	.40	15.77
Virginia	24	1	18	833	852	876	10.7	782	38	224	9,711	3,501	4,898	1,766	1.62	57.45	.82	28.98
Washington	---	--	---	10	10	10	.1	-----	40	40	------	3,536	------	(1/)	----	88.83	----	(1/)
West Virginia	85	8	100	3,870	3,978	4,063	49.8	763	38	192	8,742	4,621	3,798	2,007	1.46	68.19	.63	29.62
Wyoming	---	--	---	12	12	12	.1	-----	48	48	------	6,711	------	4,589	----	140.80	----	96.27
Total or average, bituminous	215	14	199	7,738	7,951	8,166	----	719	39	222	8,430	3,437	3,878	1,581	1.41	51.96	.65	23.90
Pennsylvania (anthracite)	8	--	8	692	700	708	----	211	29	98	7,449	3,373	9,046	4,096	1.24	108.63	1.51	131.92
Total or average, underground (including shaft and slope)	223	14	207	8,430	8,651	8,874	----	699	38	212	8,391	3,434	3,959	1,620	1.40	54.25	.66	25.60

See footnotes at end of table.

TABLE 42. - Number of injuries, by percentage distribution, average severity, and injury rates at coal mines in the United States, by State and degree of injury, 1965--Continued

State	Number of injuries: Fatal	Nonfatal: Permanent: Total	Nonfatal: Permanent: Partial	Nonfatal: Temporary total	Nonfatal: Total nonfatal	All injuries	Distribution of all injuries, percent	Average severity: Permanent partial	Average severity: Temporary total	Average severity: All injuries	Severity rates: Per million man-hours: Fatal	Severity rates: Per million man-hours: Nonfatal	Severity rates: Per million tons: Fatal	Severity rates: Per million tons: Nonfatal	Frequency rates: Per million man-hours: Fatal	Frequency rates: Per million man-hours: Nonfatal	Frequency rates: Per million tons: Fatal	Frequency rates: Per million tons: Nonfatal
Underground mines--Continued																		
Surface:																		
Alabama	---	--	---	14	14	14	1.4	-----	31	31	-----	323	-----	-----	----	10.47	----	------
Alaska	---	--	---	-----	-----	------	----	-----	--	---	-----	-----	-----	-----	----	-----	----	------
Arizona	---	--	---	-----	-----	------	----	-----	--	---	-----	-----	-----	-----	----	-----	----	------
Arkansas	---	--	---	-----	-----	------	----	-----	--	---	-----	-----	-----	-----	----	-----	----	------
California	---	--	---	-----	-----	------	----	-----	--	---	-----	-----	-----	-----	----	-----	----	------
Colorado	---	--	---	8	8	8	.8	-----	13	13	-----	232	-----	-----	----	17.48	----	------
Georgia	---	--	---	-----	-----	------	----	-----	--	---	-----	-----	-----	-----	----	-----	----	------
Illinois	1	--	---	34	34	35	3.4	-----	36	206	2,933	597	-----	-----	0.49	16.62	----	------
Indiana	---	--	---	13	13	13	1.3	-----	54	54	-----	1,457	-----	-----	----	27.09	----	------
Iowa	---	--	---	1	1	1	.1	-----	53	53	-----	2,179	-----	-----	----	41.12	----	------
Kansas	---	--	---	-----	-----	------	----	-----	--	---	-----	-----	-----	-----	----	-----	----	------
Kentucky	4	--	1	144	145	149	14.5	300	26	188	4,450	757	-----	-----	.74	26.88	----	------
Maryland	---	--	---	3	3	3	.3	-----	10	10	-----	473	-----	-----	----	45.75	----	------
Missouri	---	--	---	-----	-----	------	----	-----	--	---	-----	-----	-----	-----	----	-----	----	------
Montana	---	--	---	2	2	2	.2	-----	12	12	-----	1,163	-----	-----	----	96.89	----	------
New Mexico	---	--	---	3	3	3	.3	-----	4	4	-----	164	-----	-----	----	44.77	----	------
North Dakota	---	--	---	-----	-----	------	----	-----	--	---	-----	-----	-----	-----	----	-----	----	------
Ohio	1	--	---	29	29	30	2.9	-----	29	228	3,514	491	-----	-----	.59	16.98	----	------
Oklahoma	---	--	---	-----	-----	------	----	-----	--	---	-----	-----	-----	-----	----	-----	----	------
Oregon	---	--	---	-----	-----	------	----	-----	--	---	-----	-----	-----	-----	----	-----	----	------
Pennsylvania (bituminous)	1	1	6	86	93	94	9.2	323	51	195	895	1,832	-----	-----	.15	13.87	----	------
South Dakota	---	--	---	-----	-----	------	----	-----	--	---	-----	-----	-----	-----	----	-----	----	------
Tennessee	---	--	1	5	6	6	.6	740	13	134	-----	1,727	-----	-----	----	12.87	----	------
Texas	---	--	---	-----	-----	------	----	-----	--	---	-----	-----	-----	-----	----	-----	----	------
Utah	---	--	---	13	13	13	1.3	-----	42	42	-----	782	-----	-----	----	18.76	----	------
Virginia	1	--	3	79	82	83	8.1	800	28	128	2,647	2,045	-----	-----	.44	36.17	----	------
Washington	---	--	---	2	2	2	.2	-----	16	16	-----	1,021	-----	-----	----	63.84	----	------
West Virginia	9	--	14	545	559	568	55.4	1,261	32	157	3,885	2,523	-----	-----	.65	40.22	----	------
Wyoming	---	--	---	2	2	2	.2	-----	2	2	-----	93	-----	-----	----	61.67	----	------
Total or average, bituminous	17	1	25	983	1,009	1,026	----	922	32	159	2,855	1,704	-----	-----	.48	28.24	----	------
Pennsylvania (anthracite) 2/	---	--	3	218	221	221	----	207	32	34	-----	1,200	-----	-----	----	35.04	----	------
Total or average, surface	17	1	28	1,201	1,230	1,247	----	845	32	137	2,426	1,628	-----	-----	.40	29.26	----	------
All underground mines:																		
Bituminous coal	232	15	224	8,721	8,960	9,192	----	741	38	215	7,375	3,109	4,184	1,764	1.23	47.47	0.70	26.93
Anthracite coal	8	--	11	910	921	929	----	210	30	83	3,765	2,298	5,367	3,276	.63	72.23	.89	102.98
Total or average, deep mines	240	15	235	9,631	9,881	10,121	----	716	37	203	7,146	3,057	4,215	1,803	1.19	49.04	.70	28.92

See footnotes at end of table.

TABLE 42. - Number of injuries, by percentage distribution, average severity, and injury rates at coal mines in the United States, by State and degree of injury, 1965--Continued

State	Number of injuries						Distribution of all injuries percent	Average severity			Severity rates				Frequency rates			
	Fatal	Nonfatal				All injuries		Permanent partial	Temporary total	All injuries	Per million man-hours		Per million tons		Per million man-hours		Per million tons	
		Permanent		Temporary total	Total nonfatal						Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal
		Total	Partial															
Strip mines:																		
Alabama	1	--	---	22	22	23	2.2	-----	18	278	4,116	276	1,221	82	0.69	15.09	0.20	4.48
Alaska	--	--	---	36	36	36	3.4	-----	12	12	------	954	-----	471	----	80.05	----	39.51
Arizona	--	--	---	-----	-----	-----	----	-----	--	-----	------	-----	-----	-----	----	-----	----	-----
Arkansas	--	--	---	-----	-----	-----	----	-----	--	-----	------	-----	-----	-----	----	-----	----	-----
California	--	--	---	-----	-----	-----	----	-----	--	-----	------	-----	-----	-----	----	-----	----	-----
Colorado	--	--	1	5	6	6	.6	50	85	79	------	2,136	-----	341	----	26.98	----	4.30
Georgia	--	--	---	-----	-----	-----	----	-----	--	-----	------	-----	-----	-----	----	-----	----	-----
Illinois	6	--	4	177	181	187	17.8	259	24	221	5,405	787	1,104	161	.90	27.17	.18	5.55
Indiana	--	--	3	71	74	74	7.0	1,772	22	93	------	2,599	-----	522	----	27.95	----	5.62
Iowa	--	--	---	3	3	3	.3	-----	22	22	------	212	-----	76	----	9.63	----	3.47
Kansas	--	--	---	13	13	13	1.2	-----	16	16	------	413	-----	159	----	25.70	----	9.91
Kentucky	2	--	6	171	177	179	17.0	1,208	21	128	2,623	2,387	399	363	.44	38.69	.07	5.88
Maryland	--	--	---	1	1	1	.1	-----	29	29	------	117	-----	36	----	4.02	----	1.25
Missouri	--	1	1	29	31	31	3.0	200	18	217	------	8,778	-----	1,914	----	40.40	----	8.81
Montana	--	--	---	-----	-----	-----	----	-----	--	-----	------	-----	-----	-----	----	-----	----	-----
New Mexico	1	--	---	1	1	2	.2	-----	1	3,001	21,254	4	2,157	(3/)	3.54	3.54	.36	.36
North Dakota	1	--	1	20	21	22	2.1	200	40	319	12,063	2,029	2,179	366	2.01	42.22	.36	7.63
Ohio	3	--	7	102	109	112	10.7	316	33	210	2,467	760	675	208	.41	14.94	.11	4.08
Oklahoma	--	--	---	7	7	7	.7	-----	38	38	------	691	-----	269	----	18.05	----	7.03
Oregon	--	--	---	-----	-----	-----	----	-----	--	-----	------	-----	-----	-----	----	-----	----	-----
Pennsylvania (bituminous)	4	--	1	217	218	222	21.1	100	27	135	2,360	589	1,014	253	.39	21.43	.17	9.21
South Dakota	--	--	---	-----	-----	-----	----	-----	--	-----	------	-----	-----	-----	----	-----	----	-----
Tennessee	--	--	---	8	8	8	.8	-----	30	30	------	374	-----	111	----	12.59	----	3.75
Texas	--	--	---	3	3	3	.3	-----	18	18	------	235	-----	(1/)	----	13.28	----	(1/)
Utah	--	--	---	-----	-----	-----	----	-----	--	-----	------	-----	-----	-----	----	-----	----	-----
Virginia	--	--	1	18	19	19	1.8	3,000	14	171	------	5,322	-----	1,076	----	31.05	----	6.28
Washington	--	--	---	-----	-----	-----	----	-----	--	-----	------	-----	-----	-----	----	-----	----	-----
West Virginia	--	--	1	98	99	99	9.4	3,000	27	57	------	1,896	-----	529	----	33.44	----	9.33
Wyoming	--	--	1	2	3	3	.3	100	36	57	------	374	-----	54	----	6.57	----	.95
Total or average, bituminous	18	1	27	1,004	1,032	1,050	----	832	25	154	2,604	1,291	650	322	.43	24.88	.11	6.21
Pennsylvania (anthracite)	--	--	---	146	146	146	----	-----	24	24	------	971	-----	590	----	40.28	----	24.47
Total or average, strip mines	18	1	27	1,150	1,178	1,196	----	832	25	138	2,394	1,265	628	332	.40	26.12	.10	6.85
Auger mines:																		
Alabama	--	--	---	2	2	2	2.5	-----	22	22	------	867	-----	360	----	40.33	----	16.76
Kentucky	--	--	---	20	20	20	25.0	-----	27	27	------	674	-----	111	----	24.63	----	4.07
Missouri	--	--	---	-----	-----	-----	----	-----	--	-----	------	-----	-----	-----	----	-----	----	-----
Ohio	--	--	---	5	5	5	6.3	-----	23	23	------	444	-----	62	----	19.65	----	2.73
Pennsylvania	--	--	---	5	5	5	6.3	-----	25	25	------	634	-----	155	----	25.57	----	6.25
Tennessee	--	--	---	-----	-----	-----	----	-----	--	-----	------	-----	-----	-----	----	-----	----	-----
Virginia	--	--	---	5	5	5	6.3	-----	32	32	------	788	-----	99	----	24.32	----	3.06
West Virginia	1	--	1	41	42	43	53.8	1,140	39	203	7,471	3,415	1,256	574	1.25	52.30	.21	8.79
Total or average, auger mines	1	—	1	78	79	80	----	1,140	33	122	2,521	1,568	420	261	.42	33.20	.07	5.53

See footnotes at end of table.

TABLE 42. - Number of injuries, by percentage distribution, average severity, and injury rates at coal mines in the United States, by State and degree of injury, 1965--Continued

State	Number of injuries						Distribution of all injuries, percent	Average severity			Severity rates				Frequency rates			
	Fatal	Nonfatal				All injuries		Permanent partial	Temporary total	All injuries	Per million man-hours		Per million tons		Per million man-hours		Per million tons	
		Permanent		Temporary total	Total nonfatal													
		Total	Partial								Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal
Total:																		
Alabama	7	--	7	122	129	136	1.3	126	55	365	4,407	798	2,809	509	0.73	13.54	0.47	8.63
Alaska	---	--	---	36	36	36	.3	-----	12	12	------	954	------	471	----	80.05	----	39.51
Arizona	---	--	---	------	------	------	----	-----	--	---	------	------	------	-----	----	-----	----	-----
Arkansas	---	--	---	7	7	7	.1	-----	19	19	------	765	------	(1/)	----	39.95	----	(1/)
California	---	--	---	------	------	------	----	-----	--	---	------	------	------	-----	----	-----	----	-----
Colorado	11	--	2	107	109	120	1.2	85	30	578	25,087	1,294	13,421	692	4.18	41.43	2.24	22.17
Georgia	---	--	---	------	------	------	----	-----	--	---	------	------	------	-----	----	-----	----	-----
Illinois	14	--	14	673	687	701	6.8	936	34	172	5,137	2,218	1,439	622	.86	42.02	.24	11.77
Indiana	---	--	4	128	132	132	1.3	2,454	32	105	------	3,393	------	900	----	22.19	----	8.54
Iowa	---	--	1	12	13	13	.1	60	26	29	------	797	------	349	----	27.94	----	12.23
Kansas	---	--	---	13	13	13	.1	-----	16	16	------	413	------	159	----	25.70	----	9.91
Kentucky	41	2	33	1,574	1,609	1,650	16.0	781	31	202	6,902	2,444	2,870	1,016	1.15	45.15	.48	18.77
Maryland	---	1	---	12	13	13	.1	-----	39	498	------	10,111	------	5,199	----	20.31	----	10.44
Missouri	---	1	1	29	31	31	.3	200	18	217	------	8,088	------	1,899	----	37.22	----	8.74
Montana	---	--	---	9	9	9	.1	-----	22	22	------	1,567	------	(1/)	----	71.24	----	(1/)
New Mexico	1	--	---	15	15	16	.2	-----	31	404	11,324	881	1,874	146	1.89	28.31	.31	4.69
North Dakota	1	--	1	20	21	22	.2	200	40	319	12,010	2,020	2,177	366	2.00	42.03	.36	7.62
Ohio	8	--	10	337	347	355	3.4	695	36	189	3,438	1,359	1,211	479	.57	24.85	.20	8.75
Oklahoma	---	--	---	7	7	7	.1	-----	38	38	------	658	------	266	----	17.20	----	6.96
Oregon	---	--	---	------	------	------	----	-----	--	---	------	------	------	-----	----	-----	----	-----
Pennsylvania (bituminous)	35	2	35	988	1,025	1,060	10.3	383	48	267	4,699	1,639	2,616	912	.78	22.94	.44	12.77
South Dakota	---	--	---	------	------	------	----	-----	--	---	------	------	------	-----	----	-----	----	-----
Tennessee	11	--	2	106	108	119	1.2	438	28	587	17,972	1,048	11,466	668	3.00	29.41	1.91	18.76
Texas	---	--	---	3	3	3	(4/)	-----	18	18	------	235	------	(1/)	----	13.28	----	(1/)
Utah	2	1	3	88	92	94	.9	173	30	225	4,754	3,628	2,395	1,828	.79	36.45	.40	18.36
Virginia	25	1	22	935	958	983	9.5	885	37	214	8,373	3,348	4,404	1,761	1.40	53.48	.73	28.12
Washington	---	--	---	12	12	12	.1	-----	36	36	------	2,959	------	(1/)	----	82.57	----	(1/)
West Virginia	95	8	116	4,554	4,678	4,773	46.2	846	37	185	7,500	4,119	3,808	2,091	1.25	61.55	.63	31.25
Wyoming	---	--	1	16	17	17	.2	100	40	44	------	1,299	------	228	----	29.60	----	5.19
Total or average, bituminous	251	16	252	9,803	10,071	10,322	----	752	37	208	6,474	2,769	2,935	1,255	1.08	43.30	.49	19.63
Pennsylvania (anthracite)	8	--	11	1,056	1,067	1,075	----	210	29	75	2,931	2,004	3,219	2,202	.49	65.16	.54	71.57
Total or average, all mines	259	16	263	10,859	11,138	11,397	----	730	36	196	6,241	2,718	2,943	1,282	1.04	44.73	.49	21.09

1/ Production included in "all other" on table 39.
2/ Includes data for culm banks, dredges, preparation plants, and general repair shops.
3/ Less than 0.5.
4/ Less than 0.05.

TABLE 43. - Major disasters 1/ at coal mines in the United States, 1956-65

Date		Mine	Location of mine	Cause	Number killed
1956:	No major disasters.				--
1957:	Jan. 18	Evan Jones	Jonesville, Alaska	Explosion	5
	Feb. 4	No. 34	McDowell Co., W. Va.	do	37
	Sept. 23	Marianna No. 58	Marianna, Pa.	do	6
	Dec. 9	Glen Rogers No. 2	Glen Rogers, W. Va.	Fall of face (bump)	5
	Dec. 27	Amonate Colliery No. 31	McDowell Co., W. Va.	Explosion	11
1958:	Feb. 12	Lundale	Lundale, W. Va.	Roof fall	6
	Oct. 27	No. 34	McDowell Co., W. Va.	Explosion	22
	Oct. 28	Burton	Nicholas Co., W. Va.	do	14
1959:	Jan. 22	River Slope 2/	Port Griffith, Pa.	Inrush of water	12
	Mar. 23	No. 1	Robbins, Tenn.	Explosion	9
1960:	Mar. 8	No. 22	Holden, W. Va.	Mine fire (asphyxiation)	18
1961:	Mar. 2	Viking	Terre Haute, Ind.	Explosion	22
1962:	Jan. 10	No. 2	Herrin, Ill.	Explosion	11
	Dec. 6	Robena No. 3	Carmichaels, Pa.	do	37
1963:	Apr. 25	Compass No. 2	Dola, W. Va.	Explosion	22
	Dec. 16	No. 2	Helper, Utah	do	9
1964:	No major disasters.				--
1965:	May 24	No. 2A	Robbins, Tenn.	Explosion	5
	Oct. 16	Mars No. 2	Wilsonburg, W. Va.	Mine fire	7
	Dec. 28	Dutch Creek	Redstone, Colo.	Explosion	9

1/ A single accident in which 5 men or more are killed.
2/ Pennsylvania anthracite mine.

TABLE 44. - Injury experience and employment data on officeworkers at coal mines in the United States, by State, 1965

State	Injuries			Frequency rates per million man-hours			Severity rates per million man-hours			Men employed	Average days active	Man-days worked	Man-hours worked
	Fatal	Nonfatal	Total	Fatal	Nonfatal	Total	Fatal	Nonfatal	Total				
Alabama	-	-	-	----	----	----	-----	--	-----	133	255	33,865	270,741
Alaska	-	-	-	----	----	----	-----	--	-----	17	218	3,713	29,964
Arizona	-	-	-	----	----	----	-----	--	-----	-----	---	-------	---------
Arkansas	-	-	-	----	----	----	-----	--	-----	3	195	585	3,640
California	-	-	-	----	----	----	-----	--	-----	-----	---	-------	---------
Colorado	-	-	-	----	----	----	-----	--	-----	55	221	12,145	95,382
Georgia	-	-	-	----	----	----	-----	--	-----	-----	---	-------	---------
Illinois	-	-	-	----	----	----	-----	--	-----	268	279	74,838	602,946
Indiana	-	-	-	----	----	----	-----	--	-----	57	251	14,331	117,045
Iowa	-	-	-	----	----	----	-----	--	-----	7	197	1,376	11,008
Kansas	-	-	-	----	----	----	-----	--	-----	2	312	624	4,992
Kentucky	-	-	-	----	----	----	-----	--	-----	369	224	82,480	673,758
Maryland	-	-	-	----	----	----	-----	--	-----	11	152	1,672	14,415
Missouri	-	-	-	----	----	----	-----	--	-----	20	253	5,067	40,089
Montana	-	-	-	----	----	----	-----	--	-----	4	193	773	5,626
New Mexico	-	-	-	----	----	----	-----	--	-----	36	236	8,493	67,410
North Dakota	-	-	-	----	----	----	-----	--	-----	30	210	6,298	48,313
Ohio	-	-	-	----	----	----	-----	--	-----	322	260	83,863	679,055
Oklahoma	-	-	-	----	----	----	-----	--	-----	13	172	2,239	17,832
Oregon	-	-	-	----	----	----	-----	--	-----	-----	---	-------	---------
Pennsylvania (bituminous)	-	-	-	----	----	----	-----	--	-----	456	235	107,190	839,856
South Dakota	-	-	-	----	----	----	-----	--	-----	-----	---	-------	---------
Tennessee	-	-	-	----	----	----	-----	--	-----	23	198	4,564	35,916
Texas	-	-	-	----	----	----	-----	--	-----	9	247	2,223	17,799
Utah	-	-	-	----	----	----	-----	--	-----	76	237	17,987	140,952
Virginia	-	-	-	----	----	----	-----	--	-----	637	180	114,793	849,996
Washington	-	-	-	----	----	----	-----	--	-----	-----	---	-------	---------
West Virginia	1	-	1	0.84	----	0.84	5,063	--	5,063	663	227	150,521	1,185,091
Wyoming	-	-	-	----	----	----	-----	--	-----	24	261	6,266	49,418
Total or average, bituminous	1	-	1	.17	----	.17	1,034	--	1,034	3,235	227	735,906	5,801,244
Pennsylvania (anthracite)	-	1	1	----	2.25	2.25	-----	81	81	279	204	56,902	443,719
Total or average, all mines	1	1	2	.16	.16	.32	961	6	967	3,514	226	792,808	6,244,963

TABLE 45. - Injury, employment, production, and productivity data on bituminous-coal mines in the United States, 1930-65

Year	Number of injuries		Frequency rates				Men at work	Man-days worked (thousands)	Man-hours worked (thousands) 1/	Production, short tons (thousands)	Tons per man-hour	Number of mines
			Per million man-hours		Per million tons							
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal						
1930	1,619	71,217	1.90	83.75	3.46	152.33	493,202	92,326	850,359	467,526	0.55	5,890
1931	1,080	53,975	1.60	79.98	2.83	141.26	450,274	73,349	674,871	382,105	.57	5,652
1932	958	39,352	1.77	72.58	3.09	127.06	406,380	59,260	542,181	309,710	.57	5,473
1933	833	43,946	1.31	68.87	2.50	131.72	418,752	69,882	638,124	333,631	.52	5,629
1934	958	46,982	1.41	69.39	2.67	130.74	458,044	81,648	677,115	359,368	.53	6,290
1935	968	47,529	1.46	71.47	2.60	127.64	462,354	82,292	665,047	372,369	.56	6,332
1936	1,098	50,514	1.43	65.62	2.52	115.73	482,500	95,262	769,819	436,468	.57	6,572
1937	1,198	52,847	1.54	68.05	2.68	118.21	490,771	96,130	776,581	447,047	.58	6,537
1938	880	36,794	1.52	63.47	2.52	105.26	445,246	71,747	579,747	349,548	.60	6,531
1939	867	38,544	1.36	60.52	2.19	97.18	445,044	78,966	636,828	396,631	.62	7,274
1940	1,204	43,994	1.68	61.28	2.61	95.37	440,847	88,771	717,969	461,319	.64	7,192
1941	1,072	46,637	1.35	58.93	2.08	90.42	457,744	98,000	791,429	515,769	.65	7,401
1942	1,245	53,193	1.41	60.21	2.14	91.44	448,797	109,491	883,518	581,705	.66	6,940
1943	1,225	51,067	1.39	57.79	2.06	86.05	407,135	106,912	883,709	593,471	.67	6,490
1944	1,124	51,253	1.23	56.02	1.81	82.49	376,203	104,695	914,925	621,358	.68	6,435
1945	925	46,194	1.13	56.52	1.60	80.12	364,997	93,854	817,316	576,525	.71	6,358
1946	795	42,817	1.09	58.81	1.49	80.25	385,142	82,850	727,995	533,520	.73	6,942
1947	985	46,025	1.23	57.32	1.57	73.28	411,845	97,105	803,016	628,034	.78	9,105
1948	862	42,078	1.15	56.28	1.45	70.97	429,378	94,575	747,686	592,923	.79	9,419
1949	494	27,548	.93	51.67	1.13	63.22	409,431	67,552	533,166	435,719	.82	8,739
1950	550	28,390	.92	47.73	1.06	54.82	408,623	75,510	594,836	517,879	.87	8,817
1951	684	28,081	1.16	47.56	1.28	52.67	372,138	74,898	590,406	533,132	.90	9,679
1952	449	23,719	.90	47.64	.96	50.53	338,719	63,028	497,914	469,373	.94	8,994
1953	397	20,112	.89	45.26	.87	44.12	295,425	56,294	444,319	455,885	1.03	8,610
1954	334	14,746	.99	43.66	.85	37.62	241,919	42,765	337,727	391,952	1.16	7,934
1955	360	15,966	.96	42.76	.78	34.52	225,539	47,306	373,384	462,519	1.24	8,676
1956	392	16,486	1.02	42.99	.79	33.22	227,778	48,392	383,442	496,231	1.29	9,246
1957	427	15,915	1.17	43.74	.87	32.53	223,900	46,020	363,896	489,175	1.34	9,117
1958	326	12,036	1.14	41.97	.79	29.29	198,350	36,260	286,758	410,936	1.43	9,459
1959	246	10,440	.92	39.15	.60	25.33	180,303	33,738	266,660	412,078	1.55	9,085
1960	290	10,501	1.13	40.85	.70	25.24	170,628	32,417	257,075	416,098	1.62	9,347
1961	275	9,902	1.18	42.52	.68	24.56	151,776	29,453	232,871	403,222	1.73	8,691
1962	263	9,783	1.15	42.86	.62	23.14	147,276	28,863	228,267	422,838	1.85	8,805
1963	252	9,838	1.09	42.38	.55	21.37	143,628	29,289	232,136	460,285	1.98	8,976
1964	218	9,728	.94	41.92	.45	19.93	137,617	29,200	232,037	488,086	2.10	8,341
1965	251	10,071	1.08	43.30	.49	19.63	137,602	29,242	232,613	513,083	2.21	8,208

1/ Man-hours of exposure were reported by coal producers for the first time in 1930; from 1930 through 1944, these hours represented worktime or face-time only for underground employees. Since portal-to-portal hours were reported from 1945 on, the face-time hours reported from 1930 through 1944 were converted to portal-to-portal hours--See Bulletin 509, "Injury Experience in Coal Mining, 1948", page 5 for method used.

TABLE 46. - Injury, employment, production, and productivity data on Pennsylvania anthracite mines, 1930-65

Year	Number of injuries		Frequency rates: Per million man-hours		Frequency rates: Per million tons		Men at work	Man-days worked (thousands)	Man-hours worked (thousands)	Production, short tons (thousands)	Ton per man-hour	Number of mines
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal						
1930	444	28,764	1.76	113.90	6.40	414.56	150,804	31,568	252,543	69,385	0.27	-----
1931	383	23,983	1.84	115.07	6.42	402.09	139,431	25,915	208,415	59,646	.29	-----
1932	249	16,931	1.59	107.88	4.99	339.60	121,243	19,486	156,944	49,855	.32	-----
1933	231	15,183	1.49	98.13	4.66	306.47	104,430	19,344	154,723	49,541	.32	-----
1934	268	18,577	1.50	104.15	4.69	324.95	108,382	22,292	178,372	57,168	.32	-----
1935	274	15,897	1.78	103.16	5.24	304.17	102,848	19,280	154,096	52,263	.34	-----
1936	244	17,026	1.56	108.80	4.46	311.43	102,082	19,630	156,486	54,670	.35	-----
1937	215	13,412	1.58	98.72	4.15	259.19	99,085	18,741	135,854	51,745	.38	-----
1938	225	12,842	1.94	110.85	4.88	278.27	96,282	16,528	115,852	46,149	.40	-----
1939	211	13,229	1.71	107.37	4.11	257.65	94,331	17,524	123,211	51,346	.42	-----
1940	184	13,782	1.50	112.55	3.57	267.67	92,420	17,468	122,447	51,489	.42	-----
1941	194	14,420	1.49	110.83	3.58	266.47	88,948	18,444	130,107	54,115	.42	-----
1942	226	13,581	1.64	98.73	3.88	232.89	82,064	19,644	137,560	58,316	.42	-----
1943	226	13,527	1.50	89.68	3.80	227.32	79,381	21,385	150,832	59,506	.39	-----
1944	174	12,438	1.06	76.05	2.74	195.59	77,734	22,805	163,549	63,592	.39	586
1945	143	10,923	1.01	77.32	2.60	198.60	72,924	19,569	141,275	54,999	.39	634
1946	173	12,533	1.14	82.65	2.86	207.31	77,937	20,997	151,633	60,456	.40	665
1947	173	11,635	1.18	79.41	3.03	203.67	78,511	20,207	146,523	57,128	.39	747
1948	137	11,394	.91	75.69	2.40	199.62	77,955	20,508	150,545	57,080	.38	690
1949	91	7,857	.83	71.88	2.11	181.87	75,875	14,885	109,310	43,201	.40	592
1950	93	8,874	.80	76.14	2.09	199.75	74,616	15,721	116,554	44,426	.38	555
1951	101	7,472	.95	69.94	2.41	178.64	69,767	14,467	106,841	41,828	.39	594
1952	99	6,355	1.03	66.35	2.44	156.55	62,610	12,975	95,784	40,595	.42	570
1953	64	4,146	.92	59.85	2.10	135.85	55,701	9,275	69,275	30,518	.44	549
1954	62	2,972	1.23	59.18	2.14	102.72	41,786	6,832	50,223	28,933	.58	451
1955	60	2,919	1.30	63.46	2.07	100.84	34,550	6,285	45,995	28,948	.63	1,506
1956	56	3,330	1.12	66.31	1.74	103.36	32,507	6,893	50,220	32,216	.64	1,508
1957	51	2,877	1.15	64.93	2.00	112.69	30,825	6,057	44,311	25,530	.58	1,542
1958	32	2,124	.90	59.88	1.51	99.90	26,540	4,861	35,471	21,260	.60	1,521
1959	47	1,723	1.60	58.66	2.29	84.07	23,294	4,036	29,371	20,496	.70	1,445
1960	35	1,401	1.43	57.30	1.85	73.98	19,051	3,360	24,452	18,938	.77	1,365
1961	19	1,295	.85	57.75	1.09	73.97	15,792	3,098	22,424	17,507	.78	1,369
1962	26	1,161	1.26	56.14	1.52	67.76	14,010	2,853	20,680	17,133	.83	1,265
1963	32	1,295	1.52	61.53	1.74	70.60	13,498	2,912	21,048	18,344	.87	1,161
1964	24	1,342	1.18	65.89	1.37	76.74	13,144	2,812	20,368	17,487	.86	1,052
1965	8	1,067	.49	65.16	.54	71.57	11,132	2,271	16,375	14,909	.91	943

TABLE 47. - Injury, employment, production, and productivity data on all coal mines in the United States, 1930-65

Year	Number of injuries		Frequency rates				Men at work	Man-days worked (thousands)	Man-hours worked (thousands) 1/	Production, short tons (thousands)	Tons per man-hour	Number of mines
			Per million man-hours		Per million tons							
	Fatal	Nonfatal	Fatal	Nonfatal	Fatal	Nonfatal						
1930	2,063	99,981	1.87	90.65	3.84	186.22	644,006	123,894	1,102,902	536,911	0.49	------
1931	1,463	77,958	1.66	88.26	3.31	176.47	589,705	99,264	883,286	441,751	.50	------
1932	1,207	56,283	1.73	80.50	3.36	156.53	527,623	78,745	699,125	359,565	.51	------
1933	1,064	59,129	1.34	74.58	2.78	154.31	523,182	89,226	792,847	383,172	.48	------
1934	1,226	65,559	1.43	76.63	2.94	157.39	566,426	103,940	855,487	416,536	.49	------
1935	1,242	63,426	1.52	77.43	2.92	149.37	565,202	101,572	819,143	424,632	.52	------
1936	1,342	67,540	1.45	72.91	2.73	137.52	584,582	114,891	926,305	491,139	.53	------
1937	1,413	66,259	1.55	72.62	2.83	132.84	589,856	114,871	912,435	498,793	.55	------
1938	1,105	49,636	1.59	71.36	2.79	125.44	541,528	88,276	695,599	395,697	.57	------
1939	1,078	51,773	1.42	68.12	2.41	115.57	539,375	96,490	760,039	447,977	.59	------
1940	1,388	57,776	1.65	68.75	2.71	112.67	533,267	106,239	840,416	512,808	.61	------
1941	1,266	61,057	1.37	66.26	2.22	107.14	546,692	116,444	921,536	569,884	.62	------
1942	1,471	66,774	1.44	65.40	2.30	104.33	530,861	129,136	1,021,078	640,021	.63	------
1943	1,451	64,594	1.40	62.44	2.22	98.92	486,516	128,297	1,034,541	652,977	.63	------
1944	1,298	63,691	1.20	59.06	1.90	92.99	453,937	127,500	1,078,474	684,950	.64	7,021
1945	1,068	57,117	1.11	59.58	1.69	90.44	437,921	113,424	958,591	631,523	.66	6,992
1946	968	55,350	1.10	62.92	1.63	93.19	463,079	103,847	879,628	593,976	.68	7,607
1947	1,158	57,660	1.22	60.72	1.69	84.16	490,356	117,312	949,539	685,162	.72	9,852
1948	999	53,472	1.11	59.53	1.54	82.26	507,333	115,083	898,231	650,003	.72	10,109
1949	585	35,405	.91	55.11	1.22	73.93	485,306	82,437	642,476	478,920	.75	9,331
1950	643	37,264	.90	52.38	1.14	66.27	483,239	91,231	711,390	562,305	.79	9,372
1951	785	35,553	1.13	50.99	1.37	61.84	441,905	89,365	697,247	574,960	.82	10,273
1952	548	30,074	.92	50.66	1.07	58.97	401,329	76,003	593,698	509,967	.86	9,564
1953	461	24,258	.90	47.23	.95	49.87	351,126	65,688	513,594	486,404	.95	9,159
1954	396	17,718	1.02	45.67	.94	42.10	283,705	49,598	387,950	420,885	1.08	8,385
1955	420	18,885	1.00	45.03	.85	38.43	260,089	53,591	419,379	491,468	1.17	10,182
1956	448	19,816	1.03	45.69	.85	37.50	260,285	55,286	433,662	528,447	1.22	10,754
1957	478	18,792	1.17	46.04	.93	36.51	254,725	52,077	408,207	514,706	1.26	10,659
1958	358	14,160	1.11	43.94	.83	32.76	224,890	41,121	322,229	432,196	1.34	10,980
1959	293	12,163	.99	41.09	.68	28.12	203,597	37,773	296,031	432,574	1.46	10,530
1960	325	11,902	1.15	42.28	.75	27.36	189,679	35,778	281,528	435,036	1.55	10,712
1961	294	11,197	1.15	43.86	.70	26.61	167,568	32,551	255,296	420,729	1.65	10,060
1962	289	10,944	1.16	43.96	.66	24.87	161,286	31,716	248,946	439,972	1.77	10,070
1963	284	11,133	1.12	43.97	.59	23.26	157,126	32,200	253,185	478,629	1.89	10,137
1964	242	11,070	.96	43.86	.48	21.90	150,761	32,012	252,405	505,573	2.00	9,393
1965	259	11,138	1.04	44.73	.49	21.09	148,734	31,513	248,988	527,993	2.12	9,151

1/ All man-hours are shown on a portal-to-portal basis.

TABLE 48. - Coal-mine-fatality rates for the United States, 1870-1965 1/
(Includes underground and surface injuries)

Year	Bituminous-coal mines			Anthracite mines			Total		
	Per thousand employed	Per thousand 300-day workers	Per million tons mined	Per thousand employed	Per thousand 300-day workers	Per million tons mined	Per thousand employed	Per thousand 300-day workers	Per million tons mined
1870	----	----	----	5.93	----	13.47	5.93	----	13.47
1871	----	----	----	5.60	----	10.86	5.60	----	10.86
1872	----	----	----	4.98	----	9.20	4.98	----	9.20
1873	----	----	----	5.46	----	10.06	5.46	----	10.06
1874	2.11	----	8.88	4.33	----	9.31	3.87	----	9.26
1875	1.60	----	4.93	3.37	----	10.50	3.06	----	9.51
Average	----	----	----	4.58	----	9.94	4.30	----	9.72
1876	1.00	----	4.29	3.22	----	9.96	2.83	----	9.20
1877	2.17	----	5.90	2.90	----	7.56	2.77	----	7.28
1878	1.86	----	3.17	2.92	----	8.62	2.62	----	6.38
1879	2.02	----	3.39	3.81	----	8.67	3.30	----	6.82
1880	1.43	----	2.95	2.75	----	7.05	2.21	----	5.16
Average	1.66	----	3.42	3.12	----	8.31	2.72	----	6.68
1881	1.67	----	2.75	3.59	4.87	8.55	2.93	----	6.04
1882	1.95	----	3.63	3.54	4.87	8.29	2.75	----	5.72
1883	3.09	----	4.99	3.53	4.56	8.40	3.34	----	6.58
1884	2.26	----	4.11	3.28	5.12	8.94	2.80	----	6.17
1885	1.68	----	3.48	3.58	5.26	9.36	2.58	----	5.91
Average	2.12	----	3.88	3.50	4.94	8.72	2.85	----	6.09
1886	1.85	----	3.89	2.70	4.13	7.12	2.25	----	5.23
1887	1.55	----	3.08	2.95	4.25	7.46	2.20	----	4.86
1888	2.23	----	4.38	2.98	4.10	7.81	2.55	----	5.61
1889	1.77	----	3.44	3.11	4.81	8.45	2.36	----	5.22
1890	2.15	2.85	3.56	3.00	4.50	8.13	2.52	3.50	5.01
Average	1.94	----	3.68	2.96	4.36	7.82	2.39	----	5.19
1891	2.86	3.85	4.94	3.39	5.01	8.45	3.08	4.30	6.06
1892	3.05	4.17	5.06	3.24	4.91	7.97	3.12	4.42	5.98
1893	2.26	3.32	4.07	3.42	5.21	8.43	2.70	4.03	5.39
1894	2.26	3.96	4.65	3.38	5.34	8.57	2.67	4.50	5.91
1895	3.09	4.78	5.46	2.95	4.51	7.26	3.04	4.68	6.00
Average	2.69	4.02	4.84	3.27	4.99	8.12	2.91	4.38	5.87
1896	2.51	3.92	4.45	3.36	5.79	9.22	2.85	4.62	5.85
1897	2.38	3.64	3.99	2.82	5.64	8.04	2.55	4.27	5.08
1898	2.64	3.75	4.06	2.82	5.57	7.70	2.71	4.28	4.97
1899	3.05	3.91	4.25	3.30	5.72	7.63	3.14	4.40	5.08
1900	3.74	4.79	5.32	2.85	5.15	7.16	3.44	4.87	5.72
Average	2.90	4.06	4.46	3.03	5.58	7.94	2.95	4.50	5.34
1901	3.16	4.21	4.74	3.53	5.40	7.60	3.27	4.54	5.40
1902	3.93	5.13	5.58	2.03	5.25	7.25	3.38	5.15	5.81
1903	3.47	4.63	5.07	3.44	5.01	6.94	3.46	4.72	5.47
1904	3.35	4.98	5.26	3.82	5.73	8.13	3.48	5.17	5.88
1905	3.53	5.02	5.14	3.89	5.43	8.29	3.63	5.14	5.78
Average	3.49	4.81	5.17	3.36	5.38	7.69	3.45	4.95	5.67
1906	3.38	4.76	4.72	3.43	5.28	7.81	3.39	4.87	5.27
1907	4.99	6.40	6.46	4.23	5.77	8.27	4.81	6.25	6.78
1908	3.50	5.44	5.42	3.89	5.84	8.14	3.60	5.54	5.97
1909	4.15	5.58	5.46	3.40	4.79	6.99	3.96	5.35	5.73
1910	4.00	5.53	5.32	3.55	4.65	7.11	3.89	5.30	5.62
Average	4.01	5.57	5.50	3.70	5.25	7.67	3.94	5.48	5.89
1911	3.53	5.02	4.82	4.02	4.90	7.73	3.65	4.97	5.35
1912	3.31	4.46	4.04	3.45	4.48	7.12	3.35	4.46	4.53
1913	3.79	4.90	4.53	3.52	4.10	6.75	3.73	4.70	4.89
1914	3.19	4.90	4.40	3.31	4.05	6.55	3.22	4.66	4.78
1915	3.02	4.47	3.80	3.32	4.33	6.58	3.09	4.44	4.27
Average	3.27	4.75	4.31	3.52	4.37	6.95	3.40	4.65	4.76

See footnote at end of table.

TABLE 48. - Coal-mine-fatality rates for the United States, 1870-1965 1/--Continued
(Includes underground and surface injuries)

Year	Bituminous-coal mines: Per thousand employed	Bituminous-coal mines: Per thousand 300-day workers	Bituminous-coal mines: Per million tons mined	Anthracite mines: Per thousand employed	Anthracite mines: Per thousand 300-day workers	Anthracite mines: Per million tons mined	Total: Per thousand employed	Total: Per thousand 300-day workers	Total: Per million tons mined
1916	2.98	3.88	3.33	3.47	4.11	6.34	3.09	3.93	3.77
1917	3.50	4.33	3.83	3.77	3.98	5.84	3.56	4.25	4.14
1918	3.30	3.97	3.50	3.75	3.83	5.58	3.38	3.94	3.80
1919	2.71	4.16	3.62	4.11	4.64	7.21	2.99	4.28	4.19
1920	2.78	3.79	3.13	3.38	3.74	5.48	2.90	3.78	3.45
Average	3.05	4.03	3.48	3.70	4.06	6.07	3.18	4.03	3.86
1921	2.18	4.38	3.48	3.43	3.80	6.05	2.42	4.20	3.94
1922	2.45	5.16	3.99	1.91	3.81	5.49	2.35	4.90	4.16
1923	2.77	4.65	3.46	3.23	3.62	5.45	2.85	4.39	3.74
1924	3.08	5.39	3.94	3.10	3.39	5.64	3.08	4.80	4.20
1925	3.12	4.79	3.53	2.50	4.12	6.47	2.98	4.65	3.84
Average	2.70	4.87	3.67	2.83	3.71	5.80	2.73	4.58	3.96
1926	3.48	4.86	3.60	2.74	3.37	5.36	3.32	4.50	3.83
1927	2.93	4.60	3.36	2.96	3.94	6.11	2.94	4.43	3.73
1928	3.31	4.90	3.45	2.78	3.85	5.93	3.19	4.64	3.78
1929	3.39	4.63	3.19	3.18	4.24	6.53	3.34	4.54	3.59
1930	3.28	5.26	3.46	2.94	4.22	6.40	3.20	5.00	3.84
Average	3.27	4.84	3.42	2.92	3.90	6.04	3.19	4.61	3.75
1931	2.40	4.42	2.83	2.75	4.43	6.42	2.48	4.42	3.31
1932	2.36	4.85	3.09	2.05	3.83	4.99	2.29	4.60	3.36
1933	1.99	3.58	2.50	2.21	3.58	4.66	2.03	3.58	2.78
1934	2.09	3.52	2.67	2.47	3.61	4.69	2.16	3.54	2.94
1935	2.09	3.53	2.60	2.66	4.26	5.24	2.20	3.67	2.92
Average	2.18	3.93	2.73	2.44	3.96	5.23	2.24	3.93	3.06
1936	2.28	3.46	2.52	2.39	3.73	4.46	2.30	3.50	2.73
1937	2.44	3.74	2.68	2.17	3.44	4.15	2.40	3.69	2.83
1938	1.98	3.68	2.52	2.34	4.08	4.88	2.04	3.76	2.79
1939	1.95	3.29	2.19	2.24	3.61	4.11	2.00	3.35	2.41
1940	2.73	4.07	2.61	1.99	3.16	3.57	2.60	3.92	2.71
Average	2.28	3.65	2.51	2.23	3.60	4.23	2.27	3.64	2.70
1941	2.34	3.28	2.08	2.18	3.16	3.58	2.32	3.26	2.22
1942	2.77	3.41	2.14	2.75	3.45	3.88	2.77	3.42	2.30
1943	3.01	3.44	2.06	2.85	3.17	3.80	2.98	3.39	2.22
1944	2.99	3.22	1.81	2.24	2.29	2.74	2.86	3.05	1.90
1945	2.53	2.96	1.60	1.96	2.19	2.60	2.44	2.82	1.69
Average	2.72	3.27	1.94	2.41	2.84	3.32	2.67	3.20	2.06
1946	2.06	2.88	1.49	2.22	2.47	2.86	2.09	2.80	1.63
1947	2.39	3.02	1.57	2.20	2.57	3.02	2.36	2.96	1.69
1948	2.01	2.73	1.45	1.76	2.00	2.40	1.97	2.60	1.54
1949	1.21	2.19	1.13	1.20	1.83	2.11	1.21	1.13	1.22
1950	1.35	2.19	1.06	1.25	1.77	2.09	1.33	2.11	1.14
Average	1.80	2.65	1.36	1.73	2.16	2.54	1.79	2.56	1.47
1951	1.84	2.74	1.28	1.45	2.09	2.41	1.78	2.64	1.37
1952	1.33	2.14	.96	1.58	2.29	2.44	1.37	2.16	1.07
1953	1.34	2.12	.87	1.15	2.04	2.10	1.31	2.11	.95
1954	1.38	2.34	.85	1.48	2.72	2.14	1.40	2.40	.94
1955	1.60	2.28	.78	1.74	2.86	2.07	1.61	2.35	.85
Average	1.51	2.35	.96	1.46	2.32	2.26	1.50	2.34	1.05
1956	1.72	2.43	.79	1.72	2.44	1.74	1.72	2.43	.85
1957	1.91	2.78	.87	1.65	2.53	2.00	1.88	2.75	.93
1958	1.64	2.70	.79	1.21	1.97	1.51	1.59	2.61	.83
1959	1.36	2.19	.60	2.02	3.49	2.29	1.44	2.33	.66
1960	1.70	2.68	.70	1.84	3.12	1.85	1.71	2.73	.75
Average	1.68	2.56	.76	1.67	2.63	1.87	1.68	2.57	.81
1961	1.81	2.80	.68	1.20	1.84	1.09	1.75	2.71	.70
1962	1.79	2.73	.62	1.86	2.73	1.52	1.79	2.73	.66
1963	1.75	2.58	.55	2.37	3.30	1.74	1.81	2.65	.59
1964	1.58	2.24	.45	1.83	2.56	1.37	1.61	2.27	.46
1965	1.82	2.58	.49	.72	1.06	.54	1.74	2.47	.49
Average	1.75	2.59	.55	1.61	2.34	1.28	1.74	2.57	.58

1/ Before 1910 certain States did not maintain records of injuries. The above rates are based exclusively on tonnage and men employed in States for which injury records are available.

TABLE 49. - Bituminous-coal mines: Fatalities, by principal causes of injury, 1906-65 1/

Year	Falls of roof and face 2/	Haulage	Gas or dust explosions	Explosives	Electricity	All other underground	Total underground	Shaft and slope	Underground and shaft and slope	Surface 3/	Grand total
1906	826	192	219	115	52	27	1,431	73	1,504	77	1,581
1907	911	260	911	134	49	99	2,364	59	2,423	111	2,534
1908	829	229	320	109	53	97	1,637	53	1,690	77	1,767
1909	975	240	264	122	52	312	1,965	37	2,002	73	2,075
1910	1,061	295	477	113	76	46	2,068	60	2,128	92	2,220
Average	921	243	438	119	56	116	1,893	56	1,949	86	2,035
1911	1,007	294	331	72	92	44	1,840	31	1,871	86	1,957
1912	943	296	255	70	75	44	1,683	39	1,722	96	1,818
1913	1,007	344	464	63	79	82	2,039	32	2,071	96	2,167
1914	903	309	305	56	86	55	1,714	41	1,755	104	1,859
1915	818	269	270	76	85	35	1,553	30	1,583	100	1,683
Average	936	303	325	67	83	52	1,766	35	1,801	96	1,897
1916	850	330	183	60	81	49	1,553	34	1,587	84	1,671
1917	965	433	319	55	76	60	1,908	44	1,952	162	2,114
1918	1,052	446	103	85	77	76	1,839	41	1,880	149	2,029
1919	878	310	149	57	64	79	1,537	39	1,576	112	1,688
1920	937	342	124	82	70	72	1,627	34	1,661	120	1,781
Average	936	372	176	68	74	67	1,693	38	1,731	126	1,857
1921	782	275	62	74	76	71	1,340	25	1,365	83	1,448
1922	780	286	298	55	71	56	1,546	36	1,582	102	1,684
1923	948	347	330	66	70	64	1,825	31	1,856	97	1,953
1924	846	299	486	46	72	56	1,805	17	1,822	84	1,906
1925	910	310	302	49	80	76	1,727	30	1,757	77	1,834
Average	853	303	296	58	74	65	1,649	27	1,676	89	1,765
1926	994	384	373	46	94	62	1,953	27	1,980	85	2,065
1927	924	309	187	48	94	70	1,632	22	1,654	88	1,742
1928	825	313	347	41	82	54	1,662	13	1,675	54	1,729
1929	922	349	168	45	75	56	1,615	17	1,632	73	1,705
1930	856	285	234	31	63	68	1,537	9	1,546	73	1,619
Average	904	328	262	42	82	62	1,680	17	1,697	75	1,772
1931	624	194	68	15	62	44	1,007	19	1,026	54	1,080
1932	466	146	162	21	42	45	882	13	895	63	958
1933	458	162	27	24	46	45	762	10	772	61	833
1934	539	168	40	21	53	64	885	9	894	64	958
1935	524	198	26	31	43	70	892	13	905	63	968
Average	522	174	65	22	49	54	886	12	898	61	959
1936	624	202	41	31	44	81	1,023	11	1,034	64	1,098
1937	606	244	116	31	52	64	1,113	15	1,128	70	1,198
1938	474	142	84	23	38	53	814	9	823	57	880
1939	500	155	43	15	49	56	818	5	823	44	867
1940	520	192	292	28	30	62	1,124	12	1,136	68	1,204
Average	545	187	115	26	42	63	978	11	989	60	1,049
1941	574	191	89	24	42	65	985	9	994	78	1,072
1942	592	241	148	16	51	89	1,137	6	1,143	102	1,245
1943	592	227	166	27	33	80	1,125	5	1,130	95	1,225
1944	563	211	32	19	26	136	987	28	1,015	109	1,124
1945	453	196	72	23	20	60	824	7	831	94	925
Average	555	213	102	22	34	86	1,012	11	1,023	95	1,118
1946	442	152	27	12	17	44	694	17	711	84	795
1947	456	190	154	23	20	36	879	15	894	91	985
1948	474	148	39	22	19	41	743	18	761	101	862
1949	270	94	3	14	10	25	416	9	425	69	494
1950	313	98	3	10	11	24	459	10	469	81	550
Average	391	137	45	16	15	34	638	14	652	85	737
1951	309	101	153	7	18	24	612	6	618	66	684
1952	240	95	7	5	10	22	379	10	389	60	449
1953	233	74	9	4	12	13	345	4	349	48	397
1954	177	62	17	5	11	15	287	4	291	43	334
1955	199	61	2	10	14	15	301	2	303	57	360
Average	231	79	38	6	13	18	385	5	390	55	445
1956	215	71	5	8	14	28	341	1	342	50	392
1957	218	53	63	7	11	21	373	2	375	52	427
1958	165	43	41	7	14	18	288	1	289	4/ 37	326
1959	137	36	10	4	6	15	208	2	210	36	246
1960	151	32	3	3	18	37	244	2	246	5/ 44	290
Average	177	47	24	6	13	24	291	2	293	43	336
1961	139	38	26	4	12	23	242	--	242	33	275
1962	112	36	52	4	6	16	226	--	226	37	263
1963	123	37	31	2	5	20	218	--	218	34	252
1964	113	42	3	1	5	23	187	1	188	30	218
1965	126	34	15	1	4	28	208	7	215	36	251
Average	123	38	25	2	6	22	216	2	218	34	252

1/ Figures for 1906-09 cover only States that maintained complete records of fatal injuries. These represent 98 to 99 percent of the total production of coal in the United States. Figures for 1910 to date represent the entire bituminous coal industry.
2/ Beginning with 1963, roof falls from haulage equipment knocking out support are included in the haulage category and roof falls from machinery knocking out support and pressure bumps or bursts are included in the all other underground category.
3/ Includes strip mines and for 1955-65, includes auger mines.
4/ Includes 1 surface fatality resulting from fall of roof underground in Kentucky, 1958.
5/ Includes 2 surface fatalities resulting from the collapse of highwall, 1960.

TABLE 50. - Pennsylvania anthracite mines: Fatalities, by principal causes of injury, 1906-65

Year	Falls of roof and face 1/	Haulage	Gas or dust explosions	Explosives	Electricity	All other underground	Total underground	Shaft and slope	Underground and shaft and slope	Surface 2/	Grand total
1906	214	67	46	82	1	27	437	19	456	101	557
1907	294	88	45	87	3	57	574	27	601	107	708
1908	299	90	55	94	1	33	572	24	596	82	678
1909	254	71	31	69	6	49	480	10	490	77	567
1910	253	93	20	82	3	38	489	20	509	92	601
Average	262	82	39	83	3	41	510	20	530	92	622
1911	252	92	34	88	2	126	594	21	615	84	699
1912	243	79	35	77	5	37	476	22	498	103	601
1913	257	85	50	75	1	55	523	30	553	65	618
1914	228	76	44	90	3	45	486	47	533	62	595
1915	261	80	34	79	4	58	516	10	526	60	586
Average	248	83	39	82	3	64	519	26	545	75	620
1916	215	64	43	86	9	57	474	15	489	66	555
1917	265	64	41	55	3	39	467	16	483	99	582
1918	242	66	26	50	11	47	442	11	453	98	551
1919	229	73	42	149	4	49	546	13	559	76	635
1920	197	66	36	49	6	40	394	22	416	75	491
Average	229	67	38	78	7	46	465	15	480	83	563
1921	243	70	64	68	4	50	499	11	510	37	547
1922	128	58	13	38	3	19	259	5	264	36	300
1923	219	73	42	49	5	45	433	15	448	61	509
1924	216	58	50	53	8	45	430	12	442	54	496
1925	170	56	43	53	4	20	346	4	350	50	400
Average	195	63	42	52	5	36	393	10	403	47	450
1926	220	52	49	50	2	39	412	8	420	33	453
1927	225	52	60	62	6	43	448	7	455	34	489
1928	243	52	29	33	6	42	405	12	417	30	447
1929	260	65	27	43	6	31	432	12	444	38	482
1930	243	40	30	47	8	34	402	10	412	32	444
Average	238	52	39	47	6	38	420	10	430	33	463
1931	234	43	20	25	3	23	348	9	357	26	383
1932	161	33	7	15	5	12	233	6	239	10	249
1933	119	32	13	10	7	17	198	10	208	23	231
1934	150	29	12	15	3	25	234	8	242	26	268
1935	140	30	23	19	2	15	229	22	251	23	274
Average	161	33	15	17	4	18	248	11	259	22	281
1936	120	26	16	20	8	26	216	14	230	14	244
1937	120	31	--	14	4	16	185	11	196	19	215
1938	128	23	20	11	2	17	201	12	213	12	225
1939	121	27	3	17	2	15	185	13	198	13	211
1940	105	36	5	8	7	8	169	8	177	7	184
Average	118	29	9	14	5	16	191	12	203	13	216
1941	100	27	8	12	5	14	166	12	178	16	194
1942	132	37	9	13	6	12	209	5	214	12	226
1943	112	36	15	9	2	18	192	5	197	29	226
1944	82	16	4	16	3	18	139	12	151	23	174
1945	72	19	4	11	1	13	120	9	129	14	143
Average	100	27	8	12	3	15	165	9	174	19	193
1946	104	16	2	8	3	11	144	8	152	21	173
1947	84	14	35	7	4	3	147	6	153	20	173
1948	86	9	2	7	1	6	111	8	119	18	137
1949	54	10	3	3	-	1	71	12	83	8	91
1950	58	4	5	5	1	1	74	4	78	15	93
Average	77	11	9	6	2	4	109	8	117	16	133
1951	51	15	7	5	1	5	84	5	89	12	101
1952	51	11	4	4	-	6	76	9	85	14	99
1953	46	2	5	1	2	3	59	1	60	4	64
1954	39	6	1	--	1	2	49	2	51	11	62
1955	35	6	2	2	-	3	48	1	49	11	60
Average	44	8	4	2	1	4	63	4	67	10	77
1956	32	5	4	1	2	--	44	4	48	8	56
1957	31	5	3	4	1	4	48	1	49	2	51
1958	21	--	1	1	-	1	24	2	26	6	32
1959	30	5	--	2	-	--	37	4	41	6	47
1960	21	3	--	1	-	--	25	3	28	7	35
Average	27	4	2	2	-	1	36	2	38	6	44
1961	9	1	--	1	-	1	12	2	14	5	19
1962	8	1	--	--	-	8	17	1	18	8	26
1963	13	2	5	3	-	1	24	3	27	5	32
1964	9	3	3	3	-	2	20	2	22	2	24
1965	5	1	--	--	-	2	8	-	8	---	8
Average	9	1	2	1	-	3	16	2	18	4	22

1/ Beginning with 1963, roof falls from haulage equipment knocking out support are included in the haulage category and roof falls from machinery knocking out support and pressure bumps or bursts are included in the all other underground category.

2/ Includes strip mines, culm banks, dredges, and preparation plants.

TABLE 51. - Bituminous-coal mines: Percentage distribution of fatalities, by principal causes of injury, 1906-65 1/

Year	Falls of roof and face 2/	Haulage	Gas or dust explosions	Explosives	Electricity	All other underground	Total underground	Shaft and slope	Underground and shaft and slope	Surface 3/	Grand total
1906	52.2	12.1	13.9	7.3	3.3	1.7	90.5	4.6	95.1	4.9	100.0
1907	36.0	10.3	36.0	5.2	1.9	3.9	93.3	2.3	95.6	4.4	100.0
1908	46.9	13.0	18.1	6.1	3.0	5.5	92.6	3.0	95.6	4.4	100.0
1909	47.0	11.6	12.7	5.9	2.5	15.0	94.7	1.8	96.5	3.5	100.0
1910	47.8	13.3	21.5	5.1	3.4	2.1	93.2	2.7	95.9	4.1	100.0
Average	45.3	11.9	21.5	5.8	2.8	5.7	93.0	2.8	95.8	4.2	100.0
1911	51.5	15.0	16.9	3.7	4.7	2.2	94.0	1.6	95.6	4.4	100.0
1912	51.9	16.3	14.0	3.9	4.1	2.4	92.6	2.1	94.7	5.3	100.0
1913	46.5	15.9	21.4	2.9	3.6	3.8	94.1	1.5	95.6	4.4	100.0
1914	48.6	16.6	16.4	3.0	4.6	3.0	92.2	2.2	94.4	5.6	100.0
1915	48.6	16.0	16.0	4.5	5.1	2.1	92.3	1.8	94.1	5.9	100.0
Average	49.3	16.0	17.1	3.5	4.4	2.8	93.1	1.8	94.9	5.1	100.0
1916	50.9	19.7	11.0	3.6	4.8	2.9	92.9	2.1	95.0	5.0	100.0
1917	45.7	20.5	15.1	2.6	3.6	2.8	90.3	2.0	92.3	7.7	100.0
1918	51.8	22.0	5.1	4.2	3.8	3.7	90.6	2.1	92.7	7.3	100.0
1919	52.0	18.4	8.8	3.4	3.8	4.7	91.1	2.3	93.4	6.6	100.0
1920	52.6	19.2	7.0	4.6	3.9	4.1	91.4	1.9	93.3	6.7	100.0
Average	50.4	20.0	9.5	3.7	4.0	3.6	91.2	2.0	93.2	6.8	100.0
1921	54.0	19.0	4.3	5.1	5.2	4.9	92.5	1.8	94.3	5.7	100.0
1922	46.3	17.0	17.7	3.3	4.2	3.3	91.8	2.1	93.9	6.1	100.0
1923	48.5	17.8	16.9	3.3	3.6	3.3	93.4	1.6	95.0	5.0	100.0
1924	44.4	15.7	25.5	2.4	3.8	2.9	94.7	.9	95.6	4.4	100.0
1925	49.6	16.9	16.5	2.7	4.4	4.1	94.2	1.6	95.8	4.2	100.0
Average	48.3	17.1	16.8	3.3	4.2	3.7	93.4	1.6	95.0	5.0	100.0
1926	48.1	18.6	18.1	2.2	4.6	3.0	94.6	1.3	95.9	4.1	100.0
1927	53.1	17.7	10.7	2.8	5.4	4.0	93.7	1.2	94.9	5.1	100.0
1928	47.7	18.1	20.1	2.4	4.7	3.1	96.1	.8	96.9	3.1	100.0
1929	54.1	20.5	9.9	2.6	4.4	3.2	94.7	1.0	95.7	4.3	100.0
1930	52.9	17.6	14.4	1.9	3.9	4.2	94.9	.6	95.5	4.5	100.0
Average	51.0	18.5	14.8	2.4	4.6	3.5	94.8	1.0	95.8	4.2	100.0
1931	57.8	18.0	6.3	1.4	5.7	4.0	93.2	1.8	95.0	5.0	100.0
1932	48.7	15.2	16.9	2.2	4.4	4.7	92.1	1.3	93.4	6.6	100.0
1933	55.0	19.4	3.3	2.9	5.5	5.4	91.5	1.2	92.7	7.3	100.0
1934	56.3	17.5	4.2	2.2	5.5	6.7	92.4	.9	93.3	6.7	100.0
1935	54.1	20.5	2.7	3.2	4.4	7.2	92.1	1.4	93.5	6.5	100.0
Average	54.4	18.2	6.8	2.3	5.1	5.6	92.4	1.2	93.6	6.4	100.0
1936	56.8	18.4	3.8	2.8	4.0	7.4	93.2	1.0	94.2	5.8	100.0
1937	50.6	20.4	9.7	2.6	4.3	5.3	92.9	1.3	94.2	5.8	100.0
1938	53.9	16.1	9.6	2.6	4.3	6.0	92.5	1.0	93.5	6.5	100.0
1939	57.7	17.9	4.9	1.7	5.7	6.4	94.3	.6	94.9	5.1	100.0
1940	43.2	15.9	24.3	2.3	2.5	5.2	93.4	1.0	94.4	5.6	100.0
Average	51.9	17.8	11.0	2.5	4.0	6.0	93.2	1.1	94.3	5.7	100.0
1941	53.5	17.8	8.3	2.2	4.0	6.1	91.9	.8	92.7	7.3	100.0
1942	47.5	19.4	11.9	1.3	4.1	7.1	91.3	.5	91.8	8.2	100.0
1943	48.3	18.5	13.6	2.2	2.7	6.5	91.8	.4	92.2	7.8	100.0
1944	50.1	18.8	2.8	1.7	2.3	12.1	87.8	2.5	90.3	9.7	100.0
1945	48.9	21.2	7.8	2.5	2.2	6.5	89.1	.7	89.8	10.2	100.0
Average	49.6	19.1	9.1	2.0	3.0	7.7	90.5	1.0	91.5	8.5	100.0
1946	55.6	19.1	3.4	1.5	2.1	5.6	87.3	2.1	89.4	10.6	100.0
1947	46.3	19.3	15.6	2.3	2.0	3.7	89.2	1.6	90.8	9.2	100.0
1948	54.9	17.2	4.5	2.6	2.2	4.8	86.2	2.1	88.3	11.7	100.0
1949	54.7	19.0	.6	2.8	2.0	5.1	84.2	1.8	86.0	14.0	100.0
1950	56.9	17.8	.6	1.8	2.0	4.4	83.5	1.8	85.3	14.7	100.0
Average	53.1	18.6	6.1	2.2	2.0	4.6	86.6	1.9	88.5	11.5	100.0
1951	45.2	14.8	22.4	1.0	2.6	3.5	89.5	.9	90.4	9.6	100.0
1952	53.4	21.2	1.6	1.1	2.2	4.9	84.4	2.2	86.6	13.4	100.0
1953	58.7	18.6	2.3	1.0	3.0	3.3	86.9	1.0	87.9	12.1	100.0
1954	53.0	18.5	5.1	1.5	3.3	4.5	85.9	1.2	87.1	12.9	100.0
1955	55.2	16.9	.6	2.8	3.9	4.2	83.6	.6	84.2	15.8	100.0
Average	51.9	17.7	8.5	1.4	2.9	4.1	86.5	1.2	87.7	12.3	100.0
1956	54.8	18.1	1.3	2.0	3.6	7.1	86.9	.3	87.2	12.8	100.0
1957	51.0	12.4	14.8	1.6	2.6	4.9	87.3	.5	87.8	12.2	100.0
1958	50.6	13.2	12.6	2.1	4.3	5.5	88.3	.3	88.6	11.4	100.0
1959	55.7	14.6	4.1	1.6	2.5	6.1	84.6	.8	85.4	14.6	100.0
1960	52.1	11.0	1.0	1.0	6.2	12.8	84.1	.7	84.8	15.2	100.0
Average	52.7	14.0	7.1	1.8	3.9	7.1	86.6	.6	87.2	12.8	100.0
1961	50.7	13.8	9.5	1.4	4.4	8.4	88.0	---	88.0	12.0	100.0
1962	42.6	13.7	19.8	1.5	2.3	6.0	85.9	---	85.9	14.1	100.0
1963	48.8	14.7	12.3	.8	2.0	7.9	86.5	---	86.5	13.5	100.0
1964	51.8	19.3	1.4	.5	2.3	10.5	85.8	.5	86.2	13.8	100.0
1965	50.2	13.5	6.0	.4	1.6	11.2	82.9	2.8	85.7	14.3	100.0
Average	48.8	15.1	9.9	.8	2.4	8.7	85.7	.8	86.5	13.5	100.0

1/ Figures for 1906-09 cover only States that maintained complete records of fatal accidents. These represent 98 to 99 percent of the total production of coal in the United States. Figures for 1910 to date represent the entire bituminous coal industry.
2/ Beginning with 1963, roof falls from haulage equipment knocking out support are included in the haulage category and roof falls from machinery knocking out support and pressure bumps or bursts are included in the all other underground category.
3/ Includes strip mines and for 1955-65 includes auger mines.

TABLE 52. - Pennsylvania anthracite mines: Percentage distribution of fatalities, by principal causes of injury, 1906-65

Year	Falls of roof and face 1/	Haulage	Gas or dust explosions	Explosives	Electricity	All other underground	Total underground	Shaft and slope	Underground and shaft and slope	Surface 2/	Grand total
1906	38.4	12.0	8.3	14.7	0.2	4.9	78.5	3.4	81.9	18.1	100.0
1907	41.5	12.4	6.4	12.3	.4	8.1	81.1	3.8	84.9	15.1	100.0
1908	44.1	13.3	8.1	13.9	.1	4.9	84.4	3.5	87.9	12.1	100.0
1909	44.8	12.5	5.5	12.2	1.1	8.6	84.7	1.7	86.4	13.6	100.0
1910	42.1	15.5	3.3	13.7	.5	6.3	81.4	3.3	84.7	15.3	100.0
Average	42.1	13.2	6.3	13.3	.5	6.6	82.0	3.2	85.2	14.8	100.0
1911	36.1	13.2	4.9	12.6	.2	18.0	85.0	3.0	88.0	12.0	100.0
1912	40.4	13.2	5.8	12.8	.8	6.2	79.2	3.7	82.9	17.1	100.0
1913	41.6	13.8	8.1	12.1	.1	8.9	84.6	4.9	89.5	10.5	100.0
1914	38.3	12.8	7.4	15.1	.5	7.6	81.7	7.9	89.6	10.4	100.0
1915	44.5	13.7	5.8	13.5	.7	9.9	88.1	1.7	89.8	10.2	100.0
Average	40.0	13.4	6.3	13.2	.5	10.3	83.7	4.2	87.9	12.1	100.0
1916	38.7	11.5	7.8	15.5	1.6	10.3	85.4	2.7	88.1	11.9	100.0
1917	45.5	11.0	7.0	9.5	.5	6.7	80.2	2.8	83.0	17.0	100.0
1918	43.9	12.0	4.7	9.1	2.0	8.5	80.2	2.0	82.2	17.8	100.0
1919	36.1	11.5	6.6	23.5	.6	7.7	86.0	2.0	88.0	12.0	100.0
1920	40.1	13.5	7.3	10.0	1.2	8.1	80.2	4.5	84.7	15.3	100.0
Average	40.7	11.9	6.7	14.0	1.1	8.2	82.6	2.7	85.3	14.7	100.0
1921	44.4	12.8	11.7	12.4	.7	9.2	91.2	2.0	93.2	6.8	100.0
1922	42.7	19.3	4.3	12.7	1.0	6.3	86.3	1.7	88.0	12.0	100.0
1923	43.0	14.3	8.3	9.6	1.0	8.9	85.1	2.9	88.0	12.0	100.0
1924	43.5	11.7	10.1	10.7	1.6	9.1	86.7	2.4	89.1	10.9	100.0
1925	42.5	14.0	10.8	13.2	1.0	5.0	86.5	1.0	87.5	12.5	100.0
Average	43.3	14.0	9.3	11.6	1.1	8.0	87.3	2.3	89.6	10.4	100.0
1926	48.6	11.5	10.8	11.0	.4	8.6	90.9	1.8	92.7	7.3	100.0
1927	46.0	10.6	12.3	12.7	1.2	8.8	91.6	1.4	93.0	7.0	100.0
1928	54.4	11.6	6.5	7.4	1.3	9.4	90.6	2.7	93.3	6.7	100.0
1929	53.9	13.5	5.6	8.9	1.2	6.5	89.6	2.5	92.1	7.9	100.0
1930	54.7	9.0	6.8	10.6	1.8	7.6	90.5	2.3	92.8	7.2	100.0
Average	51.4	11.2	8.4	10.2	1.3	8.2	90.7	2.2	92.9	7.1	100.0
1931	61.1	11.2	5.2	6.6	.8	6.0	90.9	2.3	93.2	6.8	100.0
1932	64.7	13.3	2.8	6.0	2.0	4.8	93.6	2.4	96.0	4.0	100.0
1933	51.5	13.9	5.6	4.3	3.0	7.4	85.7	4.3	90.0	10.0	100.0
1934	56.0	10.8	4.5	5.6	1.1	9.3	87.3	3.0	90.3	9.7	100.0
1935	51.1	11.0	8.4	6.9	.7	5.5	83.6	8.0	91.6	8.4	100.0
Average	57.3	11.8	5.3	6.1	1.4	6.4	88.3	3.9	92.2	7.8	100.0
1936	49.2	10.7	6.6	8.2	3.2	10.6	88.5	5.8	94.3	5.7	100.0
1937	55.8	14.4	----	6.5	1.9	7.4	86.0	5.2	91.2	8.8	100.0
1938	56.9	10.2	8.9	4.9	.9	7.5	89.3	5.4	94.7	5.3	100.0
1939	57.3	12.8	1.4	8.1	1.0	7.1	87.7	6.1	93.8	6.2	100.0
1940	57.1	19.6	2.7	4.3	3.8	4.3	91.8	4.4	96.2	3.8	100.0
Average	54.6	13.4	4.2	6.5	2.3	7.4	88.4	5.6	94.0	6.0	100.0
1941	51.6	13.9	4.1	6.2	2.6	7.2	85.6	6.2	91.8	8.2	100.0
1942	58.4	16.4	4.0	5.8	2.6	5.3	92.5	2.2	94.7	5.3	100.0
1943	49.6	15.9	6.6	4.0	.9	8.0	85.0	2.2	87.2	12.8	100.0
1944	47.1	9.2	2.3	9.2	1.7	10.4	79.9	6.9	86.8	13.2	100.0
1945	50.3	13.3	2.8	7.7	.7	9.1	83.9	6.3	90.2	9.8	100.0
Average	51.8	14.0	4.1	6.2	1.6	7.8	85.5	4.7	90.2	9.8	100.0
1946	60.1	9.2	1.2	4.6	1.7	6.4	83.2	4.7	87.9	12.1	100.0
1947	48.6	8.1	20.2	4.1	2.3	1.7	85.0	3.4	88.4	11.6	100.0
1948	62.8	6.6	1.5	5.1	.7	4.3	81.0	5.9	86.9	13.1	100.0
1949	59.3	11.0	3.3	3.3	---	1.1	78.0	13.2	91.2	8.8	100.0
1950	62.3	4.3	5.4	5.4	1.1	1.1	79.6	4.3	83.9	16.1	100.0
Average	57.9	8.3	6.8	4.5	1.5	3.0	82.0	6.0	88.0	12.0	100.0
1951	50.4	14.8	6.9	5.0	1.0	5.0	83.1	5.0	88.1	11.9	100.0
1952	51.5	11.1	4.1	4.1	---	6.0	76.8	9.1	85.9	14.1	100.0
1953	71.9	3.1	7.8	1.6	3.1	4.7	92.2	1.6	93.8	6.2	100.0
1954	62.9	9.6	1.6	----	1.6	3.3	79.0	3.3	82.3	17.7	100.0
1955	58.4	10.0	3.3	3.3	---	5.0	80.0	1.7	81.7	18.3	100.0
Average	57.1	10.4	5.2	2.6	1.3	5.2	81.8	5.2	87.0	13.0	100.0
1956	57.2	8.9	7.1	1.8	3.6	----	78.6	7.1	85.7	14.3	100.0
1957	60.8	9.8	5.9	7.8	2.0	7.8	94.1	2.0	96.1	3.9	100.0
1958	65.6	----	3.1	3.1	---	3.1	74.9	6.3	81.2	18.8	100.0
1959	63.8	10.6	----	4.3	---	----	78.7	8.5	87.2	12.8	100.0
1960	60.0	8.6	----	2.8	---	----	71.4	8.6	80.0	20.0	100.0
Average	61.4	9.1	4.5	4.5	---	2.3	81.8	4.6	86.4	13.6	100.0
1961	47.3	5.3	----	5.3	---	5.3	63.2	10.5	73.7	26.3	100.0
1962	30.8	3.8	----	----	---	30.8	65.4	3.8	69.2	30.8	100.0
1963	40.6	6.3	15.6	9.4	---	3.1	75.0	9.4	84.4	15.6	100.0
1964	37.5	12.5	12.5	12.5	---	8.3	83.3	8.3	91.7	8.3	100.0
1965	62.5	12.5	----	----	---	25.0	100.0	----	100.0	----	100.0
Average	40.9	4.5	9.1	4.6	---	13.6	72.7	9.1	81.8	18.2	100.0

1/ Beginning with 1963, roof falls from haulage equipment knocking out support are included in the haulage category and roof falls from machinery knocking out support and pressure bumps or bursts are included in the all other underground category.
2/ Includes strip mines, culm banks, dredges, and preparation plants.

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BASIC COAL RESEARCH IN THE UNITED STATES

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

1968

BASIC COAL RESEARCH IN THE UNITED STATES

Compiled by Staff, Bureau of Mines–Coal Research

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UNITED STATES DEPARTMENT OF THE INTERIOR

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BASIC COAL RESEARCH IN THE UNITED STATES

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Staff, Bureau of Mines—Coal Research

ABSTRACT

Reports by researchers in government, industry, and universities of the United States are given for various projects on basic coal research concerning the metamorphism, physical and chemical properties, and reactions of coal, and how many of these studies can lead to better utilization of coal.

INTRODUCTION

As part of a continuing program of international cooperation by the United States in the field of coal research, numerous visits and written communications have been exchanged by coal research scientists in many coal producing countries. To facilitate the Bureau of Mines' participation in the program, the present report was prepared as a summary of basic coal research, excluding environmental pollution, that is underway in the United States. It was compiled in cooperation with scientists and engineers engaged in coal research in American universities, industry, and government; however, more industrial organizations than those represented in this report are very likely engaged in basic coal research. It is hoped that this report will permit a better coordination of coal research efforts and that it will assist in improved planning for the future.

AERODYNAMIC FLOW PATTERNS IN OVERBED COMBUSTION

Robert H. Essenhigh
The Pennsylvania State University

Combustion behavior of smoke and volatiles above a solid fuel bed, which can be dominated by mixing behavior (aerodynamics) of the secondary air injection, is being studied in cold, model flow systems by using air or water.

Theoretically, the ideal requirement for burnup of smoke and volatiles is that they flow into a section of a very well stirred combustion chamber; the

[1]Coordinated by Charles Zahn, research chemist, and Irving Wender, project coordinator, Pittsburgh Coal Research Center, Bureau of Mines, Pittsburgh, Pa.

"Perfectly Stirred Reactor" is the ideal. This condition can be achieved approximately by appropriate siting and manipulation of the secondary air (overbed air) jets and streams. The objective of this investigation is to determine the requirements for the optimal mixing that is possible in practice.

A plexiglas model of a combustion chamber, with means of supplying air and CO_2 tracer at the inlet or burner, has been constructed. Two methods of gas analysis at the outlet have been tested. A method of experiment is to follow the unsteady-state decay in concentration of tracer in the system. The data, according to theory, can be used to characterize a "stirring factor" in the system. Initial results indicate that this method can be done.

Problems of technique associated with the speed of response of the analyzers have to be further investigated. If they are satisfactorily resolved, the technique will be used to develop the characteristics of the stirring factors for a range of burner and secondary air injection systems.

(Research sponsored by Department of Health, Education, and Welfare of Public Health Service.)

ANALYSIS OF COAL BY RAPID METHODS

Neil F. Shimp, Charles W. Beeler, and John K. Kuhn
Illinois State Geological Survey

Rapid methods for coal analysis are of interest as a means of making analytical values more immediately available, particularly in commercial work, and lessening the cost of such analyses. Basically this project involves high temperature combustion (1,250° to 1,350° C) for determining in coal and coke such items as chlorine, ash, total sulfur, and carbon and hydrogen.

Although high-temperature methods have been used in certain European countries, they have not been widely used in the United States. In this project, applicable details of procedure and evaluation of time savings, as well as precision attainable, have been worked out. Such information should determine whether or not the methods can be dependable for both referee and control purposes or for control only.

Included in the project has been an evaluation of a semimicro-Kjeldahl method for nitrogen determination in coal. This method is more rapid than the macro-Kjeldahl determination and requires much less space for equipment.

BIOGEOCHEMISTRY OF COAL PRECURSORS

W. Spackman
The Pennsylvania State University

The main objective of this continuing program is to establish the relationships between particular geologic settings and the type of peat generated in those settings. In addition, an attempt is being made to understand and describe the manner in which various plant tissues and substances respond and

are altered in particular swamp environments. The program involves a field and laboratory study of the geological, biological, and chemical factors influencing the initial phases of coal formation. As a byproduct of the study, the information being generated will provide the basis for a detailed reconstruction of the recent geological and vegetational history of Southern Florida.

Several forested swamp environments, marsh environments, and open-water sites have been under study for the last 10 years in Southwestern Florida. The chemical composition, "petrographic character," and palynological distinctiveness of a number of the different peat types have been described. Evidence supporting the conclusion that Southwestern Florida has been undergoing transgression by the Gulf of Mexico has been presented. Techniques have been developed for recognizing peat types by their pollen and spore content or by the nature of the tissue fragments contained in the sediment, and the development of various forms of pyrite has been studied.

Plans for the future include completion of fieldwork required to permit the aforementioned reconstruction of Southwestern Florida's recent geologic history. Studies will continue in connection with describing the fate of various botanical substances in different peat-forming environments. In addition, the area under study will be expanded to include a greater portion of the freshwater Everglades in South-central Florida, with particular emphasis on areas in which extensive deposits of aquatic peats are now forming.

(Research sponsored by National Science Foundation.)

Accumulation of Organic Sediments in the Florida Everglades

W. Spackman, P. H. Given, and L. E. Casida
The Pennsylvania State University

In attempting to understand the processes by which coals come to be formed, it is clearly desirable to study the processes by which plant debris accumulates and is preserved as peat. The peat accumulations in the Everglades of Southern Florida have advantages for this purpose, because a series of environments are available for study and each is relatively simple in taxonomy.

The investigation is being conducted as an interdisciplinary study in three parallel parts:

(1) To identify the plant species characteristic of each environment by cytological study; to determine (by similar observations on samples of peat) what plant species and what anatomical components contributed to the peat at each level; to observe visually any differential alteration of the various types of plant tissues; and to draw conclusions about changes in environments with time.

(2) To characterize peats by pH, Eh, salinity, etc.; to use $^{12}C/^{13}C$ ratios to follow microbiologically induced changes in chemical components from the living plant through surface litter to the base of the peat; and to follow

the alteration of key chemical components (amino acids, carbohydrates, flavanoid pigments).

(3) To determine the level of enzyme activity in the peat; to characterize the microflora; and to ascertain what part microorganisms play in peat diagenesis.

The broad objectives and some specific objectives are clear from the above; other specific objectives are to understand more clearly the genesis of humic acids and of macerals.

A great deal of botanic information is available, so that some understanding of the geologic and floristic history of the area has been obtained and source plant material can be identified with some confidence. Certain types of cell wall in root and leaf tissues are rapidly destroyed, while others are preserved. The chemical and biochemical aspects of the research have not yet achieved firm results. Total enzyme activity appears to be high at all levels in the peat. Great difficulty has been experienced in culturing and counting microorganisms. A fluorescent staining technique has been developed which leads to bacterial counts in the range 10^7 to 10^8 per gram, but it is not clear that these organisms are responsible for alteration of the plant debris; indeed, they may be autotrophic.

In the immediate future, strong emphasis will be placed on the biochemical aspect of the research, including study of stable carbon isotope ratios. Certain freshwater areas need further botanic study, inasmuch as they represent types of environment not yet adequately investigated.

(Research sponsored by National Science Foundation.)

BIOGEOCHEMISTRY OF PEAT, BOG, AND ROCK DEPOSITS

F. M. Swain
University of Minnesota

Various types of peat deposits and organic accumulations in lakes and bogs in Minnesota are being studied from a biogeochemical point of view. The aims of the program are (1) to learn more about the diagenetic changes that occur between the source organic matter and sedimentary accumulations of organic residues, and (2) to study the relationship of biogeochemistry to the stratigraphy of deposits.

Deposits are being analyzed for carbohydrates, amino acids, hydrocarbons, organic acids, and pigments, in addition to total organic matter, humic acid, etc. Methods of studying the deposits have included, or will include, column, paper, thin layer, and gas chromatography; infrared and ultraviolet-visible spectrophotometry; mass spectrometry; nuclear magnetic resonance; electron spin resonance; and polarography.

The deposits being studied are located in glacial till and associated Precambrian and Paleozoic bedrock. They represent lake and bog sequences that

contain records of increasing eutrophication, grading to dystrophication. Many of the sequences are alkaline and marl-forming during their early history, but become more acidic in later stages of bog development.

Several rock sequences and fossils also are being studied biogeochemically. These include Jurassic rocks of the Southern and Western U.S., Middle Devonian of Pennsylvania and New York, and Precambrian of Minnesota.

CARBOXYL GROUPS IN COAL

Irving A. Breger
U.S. Geological Survey

Methods for determining the carboxyl group in coal have been investigated in collaboration with Australian colleagues. The results indicate that nearly all the published methods lead to high results.

CARBONIZATION OF COAL

David E. Wolfson
Bureau of Mines

The overall objectives of coal carbonization research by the Bureau of Mines are these: To evaluate the carbonizing properties of the principal coalbeds of the United States, to determine methods for improving the quality of the products and economics of the process, to develop new methods, and to investigate the mechanism and kinetics of the process.

A comprehensive study of the carbonization properties of coal has been a continuing program here. This study was designed to permit comparison between coals carbonized by a standard method. The method that was developed has become known as the Bureau of Mines-American Gas Association (BM-AGA) tests. By this method, coals from all geographical areas of the United States and many foreign countries have been investigated. Data from BM-AGA carbonization test at 900° C have been correlated with those obtained from commercial ovens. This survey provides the coking industry with information on the source and properties of coals and insures a continuing supply of metallurgical coals.

Coke requirements per ton of hot metal produced in blast furnaces have been decreasing steadily during the last decade, whereas demands for higher quality coke are increasing. Continuing investigations are being conducted on improving the quality of coke (the major and most valuable product from coal carbonization) by determining the effect of such process variables as temperature, bulk density, rate of heating, size consist of coal, and blending. Upgrading the poorly coking coals found in the Western United States to produce a satisfactory metallurgical coke now requires expensive shipment of low- and medium-volatile coals from other areas. Antifissurants such as char, produced in a fluidized-bed carbonizer, and coke breeze are substituted for the low- and medium-volatile coals in blends with poorly coking western coals. Acceptable metallurgical coke has been produced. This investigation is being extended to coals of other areas in the United States where coals similar in rank and properties to those in Western United States are available.

Upgrading the byproducts from coal carbonization will improve the economics of the process. An investigation showed that varying the free space above the coal charge during carbonization, which in effect permits longer residence time of the vapors at specific temperatures, improved the yields and quality of the byproducts. Because it is not practical to decrease the capacity of commercial coke ovens, a cracking unit was designed and constructed to permit simulation of the effect of residence time and temperature outside the coking chamber.

There is interest in using in a blast furnace a formed coke of uniform size, shape, and quality as a means of obtaining further decreases in coke requirements and increases in iron productivity. Furthermore, coals not normally used to make metallurgical coke in conventional coke ovens can be used to make formcoke. A pilot plant has been constructed and an investigation has been initiated to produce formcoke.

Investigations of the mechanism and kinetics of the coal carbonization process are being conducted to obtain a better understanding of the process so that more efficient utilization of coal resources can be developed. Investigation of the plastic mass that develops during carbonization is being emphasized, because it is in the temperature range of the plastic mass that the charge changes from coal to coke. Techniques such as thermogravimetry, differential thermal analysis, solvent extraction, effluent product analysis, and various analytical procedures are being used.

CATALYST DEVELOPMENT FOR COAL HYDROGENATION

Lloyd Berg
Montana State University

A program on catalytic improvement of the Bergius process has been initiated. Catalyst systems that have been used in coal hydrogenation and those that have been developed recently for denitrogenation of petroleum oil have been chosen for study. Equipment including a high-pressure, stirred autoclave for semibatch operation has been constructed and tested. The equipment allows small volume runs, about 1.5 liters, at pressures up to 3,000 psi and at temperatures to 500° C.

Catalyst studies generally involve trial and error runs that are guided by basic thermodynamic considerations of the properties of the possible intermediates. Trial and error runs will remain necessary until the kinetics and the thermodynamics of the catalyst systems can be predicted. Once preliminary runs indicate a catalyst of high activity, the effects of operating variables on yield will be determined by statistical analysis. The results of the analysis should show the optimum conditions for the catalyst system and allow an easy comparison with other catalysts.

CATALYSTS FOR COAL AND TAR HYDROGENATION

Raymond W. Hiteshue
Bureau of Mines

Acid-type catalysts are being tested for the purpose of improving the economics of hydrogenating coals and tars to liquid and gaseous fuels. Under investigation are two approaches whereby economies conceivably could be realized through improved product distribution, less hydrogen consumption, lower hydrogen costs, process simplification, or operation at lower pressures and temperatures. The first approach is the use of massive amounts of catalyst; the second is the use of hydrogen produced in situ by the reaction of steam with a metal.

Oil, predominantly gasoline, was obtained in a yield of 54 percent from an exploratory batch-autoclave operation using high-volatile A bituminous coal with an equal weight of ZnI_2 at 4,000 psi and 425° C for 1 hr. This yield approximates the gasoline yield obtained in the two-step conventional process. Production of hydrocarbon gases was also lower. These results indicated the possibility of a one-step coal-to-gasoline process with less hydrogen consumption than in the conventional process. However, in a process that utilizes a high concentration of zinc halide catalyst, it would be necessary to obtain a high recovery of catalyst at low cost to avoid excessive overall catalyst costs.

High conversions of coal to hydrocarbon gases were obtained by using large concentrations of $AlCl_3$ as catalyst in exploratory runs at 350° C and 450° C at 4,000 psi for 1 hr. The yields were 58 percent at 350° C and 68 percent at 450° C. Temperatures of 700° C and higher are required in the absence of catalyst. Thus, use of a suitable catalyst should permit large-scale hydrogasification at greatly reduced temperatures.

Exploratory batch-autoclave experiments also have demonstrated that high coal conversions and oil yields can be obtained by reacting steam, iron, and coal at 425° to 480° C and at pressures of 1,300 to 5,000 psi. Conversions and oil yields equaled or exceeded those obtainable at similar conditions by catalytic hydrogenation with molecular hydrogen. Hydrogen produced in situ apparently is more reactive than molecular hydrogen, because hydrogen partial pressures in runs with steam, iron, and coal were considerably lower than the total pressures.

Many readily available halides and other acid-type catalysts will be evaluated for liquefaction and hydrogasification of coals in a batch reactor. Low-temperature tars also will be treated.

CATALYSTS FOR FLUID-BED GASIFICATION OF COAL

Joseph H. Field
Bureau of Mines

Catalysts are being sought for increasing the rate of coal gasification with steam, which, in turn, would permit lower gasification temperatures favorable for higher methane production. Earlier work in Germany and the U.S.S.R. on catalytic studies of coal gasification was aimed mainly at accelerating the steam-carbon reaction. Another objective of this study is to find practical methods of employing the catalytic material. This search will involve use of materials that can be recovered by some separation technique or applied by flame spraying, or are inexpensive enough to be used on a once-through basis.

Standard screening tests have been made of metallic compounds principally oxides and carbonates as well as sulfides and sulfates, because the last two are probably formed in reactions with existing sulfur compounds. Materials that improved the gasification rate and yield of methane the most are Raney-nickel[2] catalyst flame-sprayed on metal inserts, $CaCO_3$, CaO, ZnO, CuO, $LiCO_3$, Pb_3O_4, MgO, and Cr_2O_3.

The reasoning that led to this project is that the economics of the production of high-Btu gas by gasification of coal with steam followed by methanation can be improved significantly by minimizing oxygen consumption and maximizing the methane yield. If, for example, the methane concentration in the raw gas leaving the gasifier is 14 percent, this will constitute about one half of the methane in the final product gas. Cost reduction will occur not only from lowered oxygen requirement, but also in capital and operating costs of the gas purification and methanation units.

CHANGES IN COAL AND LIGNITE DURING STORAGE

James L. Elder
Bureau of Mines

Correlation of the results of laboratory tests with data from observations on commercial full-scale storage of stockpiled coal and lignite is being sought. The objective is to develop a mathematical model that will permit estimation of adequately safe storage conditions with reasonable accuracy. Included in this work are measurements of rates of oxidation, rates of heat evolution, the effect of particle size, the effect of partial pressure of oxygen, and various other factors that influence the storage of coal and lignite.

[2]Reference to trade names is made for identification only and does not imply endorsement by the Bureau of Mines.

COALIFICATION

George Richard Hill, Wendell H. Wiser, and Larry L. Anderson
University of Utah

Recently some interest in the coalification process has arisen. Analyses and comparisons of information from coals of different depths and strata have been correlated with static pressure experiments. However, the effects of the interrelated parameters of temperature, pressure, time, and catalysis on the coalification process are not completely understood. Temperature seems to have the most influence on coalification. This conclusion results from evidence of increase in rank with depth, proximity to igneous batholiths, and some artificial coalification experimental results.

Research on coalification is being conducted with the following objectives:

1. Extension of artificial coalification experiments to pressures of at least 50,000 atm. This study will allow a better evaluation of the role that pressure plays in the process.

2. Artificial coalification to study the influence of inorganic elements and the possibility of catalytic action during coalification.

3. Determination of the kinetics of artificial coalification, and, if possible, an extrapolation of the information to geologic coalification. This study with appropriate analyses could also give valuable information about coal structures.

The research being done in this area is possible, in part, because of the availability of equipment that can be used to perform experiments on coal and/or other materials at high, controlled pressures (6,000 to 75,000 atm) and temperature to about 700° C.

(Research supported by Office of Coal Research, U.S. Department of the Interior, and by the State of Utah.)

COALIFIED WOOD

Irving A. Breger
U.S. Geological Survey

Coalified logs and wood fragments that were taken from uranium mines have been examined. Information was obtained on (1) the diagenetic changes that occur in wood during the biochemical stages of metamorphism, and (2) the effects of radiation from uranium and its daughter products on coal. The association of trace elements with urnaium-bearing coal is being evaluated.

COAL PROCESSING BY ELECTROFLUIDICS

Allen H. Pulsifer and Thomas D. Wheelock
Iowa State University of Science and Technology

Processes for making various chemicals from coal by utilizing an electrothermal fluidized bed are being studied. The production of hydrogen from steam and coal char has already been studied.

An electrothermal fluidized bed is a fluidized bed containing electrically conducting particles heated internally by the passage of electric current. This system offers several important advantages over other systems for carrying out reactions that are favored by high temperatures, require substantial energy inputs, and may involve corrosive reactants. These advantages are due to direct conversion of electrical energy into heat within the reacting system.

The experimental work to date has demonstrated the technical feasibility of the process for producing hydrogen. The rate of the steam-char reaction is high, from 1,600° F to 1,800° F. Operation with beds containing 50 to 60 percent ash is possible, and temperature and power control have not been a problem.

Because little has been reported in the literature on the properties of the electrothermal fluidized bed, the basic properties of the system are also being studied.

Future studies will consist of (1) continuation of the work on the hydrogen process, (2) additional measurements of the electrical properties of fluidized coal-char beds, and (3) investigations on the production of other chemicals, such as carbon disulfide and hydrogen cyanide.

COKE

Coke Improvement

James L. Elder
Bureau of Mines

A program is underway to obtain more uniform quality of coke from various western U.S. coals by using different types of blending operations. Quality is generally measured by physical strength tests.

Pilot-Plant Research on Coke

Harold W. Jackman, Roy J. Helfinstine, and L. D. Arnold
Illinois State Geological Survey

Coals from the low-sulfur areas of Southern Illinois are being proved suitable for use in metallurgical coke by laboratory and pilot-plant research. Illinois coals, by themselves or blended with eastern coals, are coked in a

pilot oven of commercial oven width. This oven, which was designed and built in our laboratory, holds 700 lb of coal, and operates under simulated commercial coke oven conditions.

Cokes produced in the pilot oven are sampled and analyzed chemically. Physical tests are made also by ASTM procedures (for strength, sizing, and gravity) and yields per pound of coal are determined. Other specialized tests, such as ash analyses or measurement of fines produced by crushing, are made when required. Experience has shown that this pilot oven coke compared closely with that made in commercial ovens in strength, size, and yield, and gives an excellent indication of commercial results that might be expected.

In addition to coke evaluation, measurements of yields of tar and gas may be made from each coal blend tested. Measurements may be made also of the pressure exerted by coal blends on coke oven walls during the coking period.

This project has been expanded to include coking of preheated coals and coal blends to determine the effect on coking time and coking properties.

Small-Scale Testing of Coke Strength

R. G. Moses
Bituminous Coal Research, Inc.

A procedure for evaluating coke strength by use of 1 lb of coal is being developed in the laboratories of Bituminous Coal Research, Inc. (BCR).

A common method for predicting the strength of metallurgical coke from the starting coal requires coking of a 500-lb charge of coal and determining the resistance to abrasion of the resultant coke by some tumbler test, such as the ASTM Tumbler Test. Coal petrography now provides a laboratory method of predicting coke stability, but such a prediction still requires confirmation by the tumbler test. To provide relative strength data to validate petrographic predictions, BCR has developed a small-scale coking furnace and is developing a test procedure to replace the 500-lb test oven and ASTM Tumbler Test.

Correlation between ASTM tumbler-derived values and the increase in surface area resulting from microtumbler degradation of laboratory-prepared coke is now being studied. A 1-lb charge of coal is coked in a special small-scale electric oven. A sized sample of the resultant coke is subjected to abrasion under standardized conditions, and the relative increase in new surface produced is used as an index for correlation with ASTM tumbler data. Correlations made to date are generally good. Microtumbler tests made on a commercial coke agree well with ASTM tumbler-derived values on the same material.

COMMINUTION OF COAL

L. G. Austin and R. P. Gardner
North Carolina State University at Raleigh

Although the grinding of coal is an important industrial operation, the theory of grinding is poorly advanced; in fact, grinding mills are designed from criteria based on prior experience. The objective of this program is to develop more precise descriptions of grinding processes, especially as applied to the range of coal types. It is hoped that this development will yield several benefits. First, it will be possible to predict the performance of a mill on any coal and for any weight-size distribution of feed. Second, the operation of the mill can be optimized for a given set of conditions. Third, the milling circuit can be more readily controlled automatically when the mathematical model of the process is known. Fourth, the development of soundly based relations between mill design and mill behavior will lead to optimal design methods.

The technique used is to describe the breakage process in the mill by two basic parameters. These are the selection parameter and the breakage function. The selection parameter, which describes how material is selected to be broken, is generally a function of particle size; therefore, a selection function is needed to describe all sizes. The breakage function describes how particles from breakage are distributed in size. These two functions are combined with mixing and residence time parameters into differential equations that describe the milling process. The equations are solved on a computer, and can be incorporated into appropriate mathematical descriptions of complete milling circuits.

The present task is to measure these functions for different types of grinding action, and explain the forms of the functions from the mechanics of the process and the properties of the coals.

In principle, the mathematical description of any particular mill and milling circuit can be accomplished with currently available experimental and computational techniques. Application of these techniques probably will take place steadily over the next few years. However, a generalization of the descriptions of selection and breakage functions and mill energy that will cover any mode of breakage is a difficult task and may take many decades of research.

COMPOSITION OF LIGNITE ASH

James L. Elder
Bureau of Mines

The elemental composition of various lignite ashes is being determined by X-ray fluorescence spectroscopy, X-ray diffraction, and standard wet methods of chemical analysis. X-ray diffraction is now being used to identify the chemical structure of some compounds obtained by normal ashing procedures. In the future, the use of modified low-temperature ashing procedures should yield

mineral matter more nearly representing that in the original lignite. Consequently, X-ray diffraction of low-temperature ashed lignite should give better information on the mineralogical composition of lignite.

COMPOSITION OF LOW-TEMPERATURE COAL TAR

Howard W. Wainwright and Clarence Karr, Jr.
Bureau of Mines

The detailed characterization of a low-temperature tar obtained from the carbonization of bituminous coal at 950° F is nearing completion. The objective of this work is to characterize the tar in sufficient detail about both individual compounds and classes of compounds so that means of upgrading this material to a marketable product can be deduced logically. Analytical techniques being used include gas-liquid and displacement-development chromatography, infrared and ultraviolet spectometry, and countercurrent distribution.

CONVERSION OF COAL

Harold Shalit
ARCO Chemical Company

In the program on the conversion of coal to liquid fuels, exploratory work is being done on hydrogenation, desulfurization, and deoxygenation of coals, as well as on catalytic reactions of coals and coal products. Work is also being carried out on devolatilization and product evaluation. The Development Division is also attempting to determine the value of coal-conversion products and their place in normal oil-refinery practice.

DEHYDROGENATION OF COAL

Leslie Reggel and Irving Wender
Bureau of Mines

The liquid-phase, catalytic dehydrogenation of coal and high-boiling coal products is being investigated on a laboratory scale mainly with the goal of developing a new method of producing hydrogen.

Palladium was used generally as the catalyst during initial dehydrogenation studies on coal. When a solid catalyst is used, a solvent (vehicle) is needed to facilitate the interaction between coal and the catalyst. Phenanthridine has been found most useful for this purpose, but other isomeric benzoquinolines as well as hydrocarbons (such as pyrene, fluoranthene, and phenanthrene) have been employed. Generally, the highest yields of gas are obtained when phenanthridine is used. The gas evolved is quite pure hydrogen. The yield seems to depend upon the chemical nature of the vehicle and its boiling point. The catalyst support has little influence on hydrogen yield, but $CaCO_3$ has been found a convenient support. In comparison of a number of catalysts containing different percentages of palladium on $CaCO_3$, the percentage of metal seemed to have only a small influence, but all of these experiments were done with high ratios of catalysts to coal. The greatest

differences were found when different metals (with the same support, concentration, and vehicle) were compared. The yields of hydrogen may be qualitatively summarized as follows: Pd > Pt, Rh, Ru, Ir > Co, Re > Ni. The Fe and Cr_2O_3-Al_2O_3 catalysts were completely inactive under the conditions used.

Dehydrogenation of a series of vitrains obtained from coals of various ranks showed marked dependence of hydrogen yield upon the rank of the coal. For coals ranging from high-volatile C bituminous to anthracite, hydrogen evolution decreases gradually with increasing rank of coal. Lignites and subbituminous coals give less hydrogen than do low-rank bituminous coals.

Tars, pitches, and high-boiling materials from hydrogenation of coal were found useful vehicles for the catalytic dehydrogenation of coal. This finding not only permits the substitution of cheap solvents in bench-scale dehydrogenation but also shows a possible way of utilizing high-boiling byproducts from coal-conversion processes.

More work is being done on the use of the cheaper vehicles. Studies also are being made on the dehydrogenation of various macerals and of coals that have been subjected to mild oxidation.

DEPOSITS FROM COMBUSTION OF LIGNITE

James L. Elder
Bureau of Mines

The nature and properties of deposits from the combustion of lignite are being studied. Lignite samples are burned in a pilot-plant combustor that simulates pulverized coal firing. Samples of the deposits from various points in the unit then are examined by X-ray fluorescence spectroscopy, X-ray diffraction, and the electron microprobe. The electron microprobe is used to determine component distribution by examining samples that are set in plastic and then sectioned. By relating the chemical distribution throughout the sectioned sample to the geometry of the reactor, information will be obtained on the mechanism of formation of the fireside deposits. Studies with the pilot-plant combustor should also yield information on the chemical and particulate emissions that cause air pollution.

DIFFUSION OF GASES THROUGH COAL

R. A. Friedel and A. G. Sharkey, Jr.
Bureau of Mines

The diffusion constants for several gases of interest to coal research and to coal mining research are being determined by use of the mass spectrometer.

In the study of the drainage of methane and other combustible gases from mines and in the investigation of oxidation and other reactions that can alter the properties of coal, it is important to know the rates of diffusion of various gases through coal and, if possible, to determine their origin. The mass

spectrometer is ideally suited for monitoring extremely low concentrations of a single component in a complex mixture such as the flow of methane through thin sections of coal; interfering contamination from other gases can be discerned.

The main purpose of this work is to determine whether aromatic molecules emitted by coal at low temperatures as found by mass spectrometry were produced in the coal at low temperatures, or were present in the coal as such and emitted from the coal through the process of diffusion. Preliminary orientation work by operating over a temperature range resulted in accurate diffusion constants and activation energies for methane. Measurements to date have been made at reduced pressures of the order of 0.1 atm. Reduced pressures facilitate the use of the mass spectrometer as a detecting device.

The principal interest in diffusion work at present is to study the transport of gases in mines. Determinations will be made at pressures up to 50 psi but with only a small pressure gradient across a thin section of coal, in simulation of flow conditions in a coal seam. Diffusion constants will be measured for the major components in mine gas with sections of coal oriented along and across the bedding plane. Diffusion rates along the bedding plane, toward the face of the mine, are of prime interest. Changes in composition of the mine gas with flow will also be investigated. The origin of mine gas will be investigated by studying the distribution of stable carbon isotopes.

DIFFUSION OF METHANE IN ACTIVATED ANTHRACITE

P. L. Walker, Jr.
The Pennsylvania State University

Unsteady-state diffusion of methane into a -42+65 mesh Pennsylvania anthracite with low-volatile matter (4.0 percent) is being studied between 27° to 75° C to determine the effect of slight enlargement of the molecular-sized pores in coal on activated diffusion of gases into (or out of) the pores. The anthracite has been previously devolatilized at 950° C in nitrogen and activated to different levels of burn-off by air activation at 425° C. The high-pressure apparatus used to make the diffusion measurements has been described previously.[3]

The samples (-42+65 mesh particle-sized) burned off to less than 6.2 percent could not be studied conveniently in the present apparatus and under the conditions selected because diffusion was very slow. For burn-offs between 6.2 and 8.2 percent, diffusion of methane into the coal increases rapidly and the activation energy for diffusion decreases from 7.9 kcal/mole to nil. These results clearly show that small burn-offs can markedly alter the ease of gas diffusion in coal and suggest the possibility of producing various types of molecular sieve carbons from coal by strict control of activation in the low burn-off range.

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[3]Kini, K. A., and P. L. Walker, Jr. A Simple Apparatus for Measurement of Adsorption Gases From Low to High Pressure. J. Sci. Instruments, v. 42, 1965, pp. 821-822.

It is planned to study (1) diffusion of methane in smaller particle sizes of the anthracite so that data can be obtained at smaller burn-offs, and (2) the possibility that cracking of methane in the pores of the anthracite at above 800° C to yield carbon will reduce pore accessibility.

(Research sponsored by Coal Research Board of the Commonwealth of Pennsylvania.)

DISSOLUTION OF COAL IN SOLVENTS

George Richard Hill, Wendell H. Wiser, and Larry L. Anderson
University of Utah

Studies have been made on the dissolution of untreated coal principally in hydrocarbon solvents. The objective has been to gain information about the chemical nature of the reacting coal and to understand the specific chemistry of the solution process.

Data have been obtained in Soxhlet extraction of coal by several dozen solvents. Research has been carried out in each of the four solvent extraction categories suggested by van Krevelen.[4] The influence of ultrasonic energy on the extraction yield and the kinetics of dissolution of 1,2,3,4-tetrahydronaphthalene have been studied.

The obtained kinetic data show that the activation energy for extraction of coal with tetralin at temperatures above 350° C is about 30 kcal/mole for the second-order reaction. During the dissolution process, the reaction finally becomes first order with an activation energy of 15 kcal/mole. The first kinetic data obtained for solution of coal in tetralin above 350° C and for solution of coal in tetralin accompanied by ultrasonic energy were obtained in our laboratory. This work disproved the long-held theory that extraction of coal was a zero-order solution reaction and a first-order precipitation reaction.

The extraction of coal in an ultrasonic field has been shown to have an activation energy of about 6.7 kcal/mole. These studies have also demonstrated that both the rate of reaction and the yield at a particular temperature are affected by ultrasonic energy.

Future work on dissolution of coal should be directed toward a better understanding of the process. This can be accomplished if suitable analyses can be made on the extract to show what particular species and chemical bonds are being dissolved or broken. The specific effects on the process by ultrasonic or other energy sources can also be elucidated by careful analyses of the products of the solution reaction.

(Research supported by Office of Coal Research, U.S. Department of the Interior, and by the State of Utah.)

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[4] van Krevelen, D. W. Coal. Elsevier Publishing Company, New York, 1961, pp. 185-186.

ELECTROCHEMICAL TREATMENT OF COAL

Heinz W. Sternberg and Irving Wender
Bureau of Mines

New methods of electrochemical reduction have been discovered at the Bureau of Mines and are being used experimentally for the electrochemical treatment of coal, coal products, and coal-derived chemicals.

Initial studies on the use of ethylenediamine as the solvent medium in electrochemical reduction have been reported. The objectives of the current work are (1) to find an inexpensive solvent of potentially industrial value, (2) to develop methods for obtaining and using coal-derived products by electrochemical reactions, and (3) to use electrochemistry to acquire more insight into the nature of coal.

A fundamental reductive system of universal applicability was discovered while developing a method for the electrochemical reduction of coal. Reduction is achieved by electrons being generated at the electrode and being released into the solvent to form the solvated electron, which is one of the most powerful reducing agents known and which is capable of reducing the isolated benzene ring as well as the isolated double bond. Moreover, the substrate need not be soluble to undergo reduction; this is an important advantage for electrochemical reduction of coal and other insoluble materials.

Work now in progress has already demonstrated that ethanol containing hexamethylphosphoramide can be used for generating solvated electrons and that this solvent system can be used for reducing coal. It is hoped that means eventually will be found for using water as a solvent in the electrochemical treatment of coal.

Other experiments gave results potentially valuable for the utilization of coal tar products. By appropriate choice of electrode material and operating conditions, selective hydrogenation of aromatic hydrocarbons (including the benzene ring) was achieved. Consequently, in contrast to conventional methods of catalytic hydrogenation that usually give fully saturated and hence unreactive products, electrochemical hydrogenation can be so conducted that one or two reactive double bonds will remain intact in the hydrocarbon. Such a reaction is potentially valuable, because cyclic hydrocarbons with olefinic (double) bonds in specific positions on the molecule are in demand for filling the ever-increasing needs of the plasticizer and polymer industries.

Perhaps the most important lesson learned from these studies is that coal behaves essentially as a hydroaromatic hydrocarbon and that conventional methods of treating or using coal do not take full advantage of the inherent reactivity of coal. In keeping with this line of approach, solubilization of coal was achieved by treatment of coal with lithium in hexamethylphosphoramide, and then alkylating by nondestructive organic methods that are applicable to aromatic and hydroaromatic hydrocarbons. The product was 90 percent soluble in pyridine and 30 percent soluble in benzene at room temperature, and it contained about one methyl group per 100 carbon atoms. These findings indicate

a promising method for modifying the physical and chemical properties of coal by introducing various functional groups into the coal molecule.

ELECTRON MICROSCOPY OF COAL AND RELATED MATERIALS

Sabri Ergun
Bureau of Mines

The general objective of our continuing program on the use of electron microscopy is to observe and characterize, insofar as possible and practicable the ultrafine structure in coals, coal components, cokes, and related carbonaceous materials. Immediate objectives are these: To study the association of very fine mineral matter with different coal components and to determine its crystalline phases by electron diffraction, to study the regular shapes of particles of ultrafine granular micrinite and their relation to crystallites of graphite, to explore the usefulness of darkfield electron microscopy in clarifying structures previously observed in various components, and to observe development of ultrafine pore structure in semicokes.

EVALUATION AND DEVELOPMENT OF SPECIAL PURPOSE COALS

W. Spackman
The Pennsylvania State University

This program includes the following studies:

1. The extent to which anthracite and other coals (a) react dissimilarly to conversion and other processes including (but not limited to) gasification, hydrogasification, and liquefaction, (b) serve as sources of catalyst poisons in these same procedures, and (c) react dissimilarly in sewage treatment and other processes employing coal as a raw material.

2. The description of efficient techniques for concentrating the common coal types in commercially attractive sizes and quantities.

3. The identifying characteristics of anthracite and other coals now employed or anticipated for use by Office of Coal Research (OCR) contractors. The primary objective of this facet is to establish the identity of each experimental sample in compositional terms that will render attendant experimental data more interpretable with respect to knowledge contained in the literature and information to be acquired in the future.

4. The technically and economically feasible methods of producing and classifying coals and coal types of 100-mesh size with minimal variation in size.

5. The physical separation of sufficient quantities of distinctive coal types for use in bench-scale testing in chemical, conversion, and other processes being explored by OCR contractors.

6. The improvement of methods for utilizing anthracite, based on detailed experimental investigation of ultrafine grinding.

Petrographic studies of 73 coal samples have been completed including development of data on maceral composition and vitrinite reflectance. Routine proximate and ultimate analyses have been completed on 72 coal samples. More than 30 different coal types have been collected in samples varying between 200 and 500 lb. Petrographic, chemical, and physical studies of these samples have been initiated. One-ton channel samples have been collected at the sites from which the various lithotypes were obtained; beneficiation studies have been initiated to assess the feasibility of segregating certain of the lithotypes from a run-of-mine product.

Future plans call for the completion of studies on at least 20 of the lithotypes. Conferences with other OCR contractors are envisioned as a means of optimizing coal composition in connection with each industrial process under evaluation and study. In addition, lithotypes which appear to be particularly suited to certain processes will be tested in small-scale pilot units.

(Research sponsored by Office of Coal Research, U.S. Department of the Interior.)

FIRESIDE CORROSION IN COAL-FIRED STEAM GENERATORS

A. A. Orning
Bureau of Mines

The Bureau of Mines has maintained a continuing research program on fireside corrosion ever since corrosion first appeared on the water-cooled wall tubing of slagging furnaces where temperatures on the tube surface are about 750° F. Corrosion later appeared on the superheater and reheater tubes where temperatures of the metal may approach 1,200° F.

Deposits adjacent to the corrosion differ in composition from that of fly ash. Corrosion deposits from American coals show high concentrations of alkali metals, iron, and either sulfates or pyrosulfates. A sulfate, analogous to tripotassium ferric trisulfate, probably is a major component in corrosion at 1,200° F, whereas a corresponding pyrosulfate is the major component at 750° F.

Studies revealed that (1) alkali metals migrate towards colder surfaces in a layer of fly ash in a high-temperature gradient; (2) fly ash, in an atmosphere of synthetic flue gas, tends to absorb sulfur oxides which produce a maximum sulfate concentration at about 1,200° F; (3) mixtures of sodium, potassium, and iron sulfate react and become fluid at similar temperature levels; (4) alkali sulfates on steel surfaces react with flue gas to form liquid phases at temperatures below the melting points of the sulfates; and (5) alkali chlorides, deposited on steel surfaces at 700° F, are converted to sulfates by contact with hot flue gas.

Alleviation of fireside-corrosion problems has resulted primarily from equipment design to avoid metal-surface temperatures within critical temperature ranges. This has limited the advance to higher steam temperatures and consequently has limited advances to higher thermal efficiencies in production of electric power. Advances to higher steam temperatures may be possible if alloys are developed to withstand direct gas-phase oxidation and if deposit temperatures become such that the complex alkali-metal iron sulfates are no longer stable.

The Bureau's future work will extend the work on high-temperature corrosion and will put emphasis on the reaction between flue gas and the alkali-metal salts on metal surfaces. This research should indicate the temperatures at which the reactions occur and those above which the resulting products decompose so that the liquid-phase corrosion medium can no longer exist.

FLASH AND LASER IRRADIATION OF COAL

R. A. Friedel and A. G. Sharkey, Jr.
Bureau of Mines

Flash and laser irradiation of coal are being investigated to determine the conditions necessary for obtaining the optimum yield of products when coal is rapidly heated to the extreme temperatures produced by such irradiations.

The laser is a light source capable of producing very intense radiation. Absorption of the radiation by a good absorber such as coal produces temperatures of the order of several thousands of degrees centigrade. Under these conditions, valuable chemicals such as acetylene and HCN are produced from coal. Appreciable amounts of other components, primarily unsaturated hydrocarbons, are also formed by laser irradiation. Products have been studied as a function of coal rank; an investigation of the products from the irradiation of Pittsburgh seam hvab coal in various inert atmospheres has been completed. Gases from several coal macerals were also studied.

Present studies include an investigation of product yield as a function of the particle size of coal. Investigation of the material balance for laser irradiation of hvab coal is continuing with emphasis on determining the composition of the residue. A study of the temperature of the coal and gases during irradiation is continuing in cooperation with the Flame Dynamics Group of the Bureau of Mines Explosives Research Center. Product yield from coal impregnated with various catalysts, including metal carbonyls, is being investigated. Laser irradiation under various thermal conditions and with focused and defocused beams is being explored. Experiments to obtain a material balance and to determine products from model compounds are continuing.

Products from the laser irradiation of untreated coals such as oxidized coal will be investigated by using pulsed and continuous laser energy. A small unit will be designed for the continuous irradiation of coal possibly by using a continuous CO_2 laser to irradiate a fluidized bed. An attempt will be made to determine if there is a specificity of products for various frequencies of irradiation. A limited number of laser irradiations at frequencies

other than 6,943 A will be attempted. Irradiation of various coal carbonization products such as tar vapor collected on carbon will also be attempted.

FLUIDIZED-BED COMBUSTION OF COAL

A. A. Orning
Bureau of Mines

Fluidized-bed combustion of coal has attracted interest as a possibly new and major development. Work at the Bureau of Mines is being coordinated with that of the United Kingdom National Coal Board, which is investigating the practical application of the process to energy production. The Bureau is concentrating upon fundamental problems of the process at two research stations.

Operations at the Pittsburgh station include pneumatic injection of crushed coal into a fluidized bed of refractory grog (with an original settled depth of 8 to 10 in) that is held in a water-cooled cylinder of 17-in inside diameter.

The experimental data, together with a theoretical analysis of the thermal balances that control bed temperatures indicate different modes of operation in the excess- and deficient-air ranges. The refractory grog is used in the excess-air range to provide sufficient heat-transfer area for heat transfer from the bed. Fuel investory in the bed approaches zero with increasing bed temperature and excess air. Operation in the deficient-air range requires a high fuel inventory and limited air supply. Decreased heat release per unit of air consumed, owing to hydrogen and carbon monoxide displacing carbon dioxide and water as end products, causes a complete inversion in the effects of control variables.

Direct heat transfer from the fluidized bed is an attractive feature of the fluidized-bed combustion system. Work by the Bureau has indicated heat-transfer coefficients in the range from 30 to 100 Btu/sq ft-hr-° F, which increase with fineness of the fluidized-bed material.

FOOD FROM COAL

Carl Rampacek
Bureau of Mines

The use of low-grade coal is being investigated as a substrate for growing edible microorganisms that can be used as a source of high-protein food. Current emphasis is on the development of a set of environmental and nutritional conditions that will enhance the growth of protein-rich microorganisms on water extracts of leonardite, a naturally oxidized lignite.

Deposits of low-grade coal are very large and widespread in the United States and throughout the world. If an economically feasible method were developed to utilize such reserves, the world food supply would be increased greatly, and, perhaps more importantly, make large supplies of essential

proteins available in regions where high-protein food is now difficult to obtain. Microorganisms contain 30 to 80 percent protein and the amino acid composition of this protein approximates that of whole milk or beef; therefore they could supply essential amino acids if the energy associated with cell development could be supplied from inexpensive substrates.

The literature describes microorganisms growing on the surface of coal and also reports attempts to grow microorganisms on specific products or pure compounds derived from coal. However, the use of coal, with little or no prior processing, as a substrate for the growth of microorganisms apparently has not received much scientific effort. Coal is an attractive source of energy for growth of protein-rich microorganisms, because it is the least expensive, most abundant, readily available carbon source.

GEOCHEMISTRY OF METAL-ORGANIC COMPLEXES

Peter Zubovic
U.S. Geological Survey

Complexing of metals with organic materials found in the geological environment is being studied to secure information that will elucidate the distribution of metals in carbonaceous materials such as coal, lignite, peat, and black shales.

Two humic acids (one extracted from a lignite, and the other from peat) are being examined by gel filtration, infrared and chemical analysis to determine molecular weights and chemical differences. The fractions of lower molecular weight will be further separated by gas-liquid chromatography and electrophoresis.

Preliminary studies of humic acids complexed with iron and gold have been made and more detailed work is in progress. Complexes are being studied by some of the procedures mentioned above as well as by potentiometric methods.

Additional elements of interest in the organic geological environment such as those of the first transition group, germanium, gallium, and heavy metals (silver and gold), will be studied extensively. Other components of naturally occurring organic matter, such as porphyrins and amino acids, also will be studied. In addition, laboratory findings will be supplemented by studies on the distribution of metals in selected organic deposits.

HIGH-RESOLUTION MASS SPECTROMETRY OF COAL-TAR PITCH

R. A. Friedel and A. G. Sharkey, Jr.
Bureau of Mines

Coal-tar pitch is being studied by high-resolution mass spectrometry to determine changes in the organic structures in road tar during weathering and to enable prediction of changes in pitches, such as electrode binder material, in various atmospheres. Little is known about the changes in the organic species in pitch during exposure to various atmospheres. Factors producing

deterioration of road tars during weathering could have their origin in these changes. Similarly, a detailed study of organic species in pitch could contribute to an understanding of factors responsible for "good" and "poor" electrode binder pitches.

High-resolution mass spectrometry offers a new approach to studies of organic structure containing nitrogen, oxygen, and sulfur. Changes in the organic species in altered fractions of pitches could involve changes in structures containing these heteroatoms. A detailed study has been made of a pitch (softening point, 80° to 85° C) to obtain background material for this investigation. Empirical formulas were obtained for 162 components containing carbon, hydrogen, oxygen, nitrogen, and sulfur.

HYDROGENATION OF COAL AND COAL TAR

George Richard Hill, Wendell H. Wiser, and Larry L. Anderson
University of Utah

Hydrogenation studies in our department have developed along four paths: (1) evaluation of catalysts for hydrogenation in batch and continuous processes for maximum yield of liquids, especially those boiling below 230° C, (2) determination of the order of reaction and other kinetic data, (3) development of a plausible explanation for the chemical mechanism of the hydrogenation process, and (4) study of the effects of very short residence times (less than 1 sec) and of fine particles (5μ to 10μ) on the hydrogenation reaction.

The information available at the present time can be summarized as follows:

1. Western bituminous coals can be hydrogenated to produce liquids in yields greater than 50 percent of the weight of the original coal, maf, at 3,000 psi of hydrogen. This result can be accomplished best by batch hydrogenation at 500° C for a reaction time of 2 hr in the presence of ammonium molybdate and a vehicle-oil carrier. The same yield of liquids can be obtained in a continuous process at 515° C with a residence time of 0.5 sec and use of tin chloride catalyst.

2. Kinetic studies indicate that coal hydrogenation is generally much faster than hydrogenation of coal tar. Maximum conversion of coal to products takes about 2 hr in a batch process and 0.5 sec in the continuous reactor, whereas hydrogenation of coal tar requires more than 10 hr to obtain a maximum yield. The catalytic hydrogenation of coal involves an activation enthalpy of 20 to 22 kcal/mole; the value for hydrogenation of coal tar is 10 kcal/mole.

3. The rate of coal hydrogenation is effected best by use of small particles (minus 200 mesh). Additional work should be done to obtain information on the hydrogenation of very small microsized particles.

4. Apparently the fundamental coal micelles, consisting of some fused aromatic rings, are neither being hydrogenated nor broken up to any appreciable extent before hydrogenation when coal is the feed material. Evidently

the severing and hydrogenation of the atoms or chains between these micelles is a much faster process than hydrogenation of the aromatic clusters. Apparently, a suitable material to catalyze both of these reactions has not been successfully applied.

Studies have been initiated involving catalytic hydrogenation of pure fused aromatic compounds. It is desirable to understand, if possible, the points of initial attack by hydrogen upon the multiring nucleus. It is also of interest to determine whether a center ring in a multiring nucleus can be hydrogenated and ruptured without hydrogenating the rings at the end of the fused structure. It is hoped that these studies on pure compounds may produce answers to some of these questions.

Work that is indicated by the present status of our research and the work of others in this area includes hydrogenation of coal wherein the residence time can be controlled in the range 0.5 to 120 sec, and investigation of other catalysts that may cause a breakup of the fused aromatic coal structure under hydrogenation conditions.

(Research supported by Office of Coal Research, U.S. Department of the Interior, and by the State of Utah.)

ISOTOPIC LEAD COMPOSITION OF COALS

Tsaihwa J. Chow and John L. Earl
Scripps Institution of Oceanography

The concentration and isotopic composition of lead in various ranks of coal from the principal coal producing regions of the United States was investigated. More than 100 samples from mines representing 40 percent of the total annual United States coal production have been analyzed for lead by mass spectrometry. Lead concentrations in these coals range from 0.7 to 38 ppm in the raw coal (7 to 350 ppm in the ash), with the average between 5 to 10 ppm. The preliminary data suggest a regional variation in lead concentration, depending to some extent on the provenance and age of the coal.

Isotopic compositions of the lead in coals indicate that each coal seam may have a certain distinctive composition range which is characteristic of that particular seam or group of closely related seams. This observation may prove valuable to geologists seeking to correlate seams in different coalfields.

The annual production of various grades of coal in the United States has averaged 500 million tons per year over the past five decades. Assuming that this coal has an average lead concentration of 5 to 10 ppm, as results thus far indicate, an estimated 2,500 to 5,000 tons of lead are contained in the coal that is consumed each year. Presently we are attempting to determine what percentage of this lead is introduced into the atmosphere by volatilization during the burning process.

JET

Irving A. Breger
U.S. Geological Survey

The chemical nature and composition of jet is being investigated in collaboration with English colleagues.

KINETICS OF THE COMBUSTION REACTIONS OF CARBON

Sabri Ergun
Bureau of Mines

A program on the combustion reactions of carbon presently concerns the devolatilization of chars produced by processing of coal, for example, chars resulting from thermal or chemical treatment of coal. An investigation of the direct devolatilization of coals of different rank is planned.

Chars are produced (frequently in large quantity) as a byproduct of various types of coal processing. Although they are a secondary product, uses must be found for these chars. In both combustion and gasification, the most commonly proposed uses, volatile matter is liberated and undergoes reaction. The release and reaction of volatile matter probably precede and may be partially concurrent with reaction of the carbon residue of the solid. Therefore, meaningful studies of the rates of combustion or gasification of chars and coals require knowledge of the kinetics of devolatilization. At present, little is known about the rates and amounts of volatiles produced under different conditions of heating.

LASER MICROPYROLYSIS OF COAL

F. J. Vastola and P. H. Given
The Pennsylvania State University

A laser micropyrolysis instrumental system is being used with the objective of securing chemical information about the components of a heterogeneous solid by inspection of the materials in situ. Coals treated with a relatively low-energy ruby laser produce fragments of mass number up to 300. Complex spectra are obtained, but they show certain regularities, and there is hope that they can be interpreted in terms of chemical structures. Repeated analyses of the same maceral are closely reproducible, whereas different macerals give obviously different spectra. Progressive changes in spectra are observed with change in rank.

The experimental technique is as follows: A sample with a polished surface, about 3 by 15 mm, is mounted in the ionization chamber of a time-of-flight mass spectrometer; a vacuum lock permits introduction of samples without loss of vacuum in the ionization chamber. A microscope is positioned to examine the sample through a window in the top of the ionization chamber, and to select an area for study. A short pulse (200 msec or less) of energy from a laser is projected through the microscope objective on to a small area

($10\text{-}\mu$ to $200\text{-}\mu$ diameter) of the solid. The vapor species produced by pyrolysis are ionized by a 0.5μ-sec emission from an electron gun, and the ions then proceed down the drift tube and are analyzed. The mass spectra are displayed on an oscilloscope and photographed.

It is planned to use the technique for distinguishing various macerals not adequately characterized at present and for studying in a series of vitrinites the chemical effects of metamorphism.

(Research sponsored by National Science Foundation.)

LIQUEFACTION OF COAL

Herbert R. Appell and Irving Wender
Bureau of Mines

A method is being developed for the liquefaction of coal by treatment at high pressure with carbon monoxide and water, but without the use of molecular hydrogen or added catalyst. The liquefaction appears dependent on pressure, temperature, and the presence of certain solvents.

Consistently more coal liquefaction resulted when carbon monoxide and water were used than when hydrogen was used under similar operating conditions. Treatment of Pennsylvania seam coal (minus 100 mesh) and an equal amount of phenanthrene (as solvent) with 1,000 psi hydrogen (initial pressure) at 400° C for 2 hr resulted in 34 weight-percent benzene-insoluble product, but treatment with carbon monoxide and water instead of hydrogen gave 29 percent benzene-insoluble material.

As expected, lignite was more reactive. Treatment of North Dakota lignite with an equal weight of 1:1 phenanthrene-naphthol (as solvent) at 1,000 psi and 377° C for 1 hr gave 21 percent benzene-insoluble material when using hydrogen and 16 percent when using carbon monoxide and water. The reaction was poorer when phenanthrene alone was used as the solvent. The reaction rate increased directly with increase in pressure. At an initial pressure of 1,500 psig, the benzene-insoluble residue was 7 percent after operation for 1 hr at 377° C. The optimum temperature apparently is between 375° C and 400° C. At 365° and 408° C, the yield of benzene-soluble product is significantly less.

If no solvent is used with coal or lignite, the results are poorer; higher pressures are required to obtain good yields of benzene-insoluble product.

The mechanism of the liquefaction of coal and lignite by carbon monoxide and water will be investigated by use of model compounds alone and in the presence of various catalysts.

METAMORPHISM OF COAL

Irving A. Breger
U.S. Geological Survey

Studies aimed at evaluating the influence of shear (at relatively low temperature and under low confining pressure) on the origin of coal are being made. The effect of shear on humic acid has been studied in initial experiments.

Geochemistry and Diagenesis

P. H. Given, W. Spackman, F. J. Vastola, and P. L. Walker, Jr.
The Pennsylvania State University

The geochemistry of coal metamorphism and diagenesis is being investigated to establish the nature of various coal metamorphic series at the maceral and lithotype level of organization and to clarify the role of various geological, chemical, and biological factors related to the metamorphosis of macerals and lithotypes.

The current lines of investigation include the following:

1. Causal relationships between environmental conditions of coal diagenesis and lithotype distribution. The lithotype composition of the Lower Kittanning seam in Western Pennsylvania has been correlated with the depositional environment of sediments overlying the coal seam, which were known from previous stratigraphic and paleontological research. Other seams will be investigated in a similar way.

2. Chemical distinctions between macerals. Optical methods of differentiation are sometimes ambiguous, or do not adequately characterize the material seen. Chemical data will be obtained using a laser micropyrolysis system to aid differentiation of the following: (a) vitrinite and pseudovitrinite, (b) vitrinitic material in the vitrain, clarain, and durain of the same coal, (c) various exinitic macerals, such as sporinite, alginite, and cutinite, and (d) certain resinites and vitrinites.

3. Relation of free radicals to thermal history. It has been found that the thermal history of carbonaceous solids can sometimes be deduced from their free radical content and changes in radical content arising on laboratory carbonization. Fusinites and a coal subjected to contact metamorphism have given useful results by carbonization in conjunction with electron spin resonance spectrometry. It is proposed to extend the spectrometric technique to other thermally altered coals.

4. Systematic differences in correlations of coal rank and property for different major coalfields, as a result of differing metamorphic conditions. Correlations between reflectance, elementary composition, volatile matter, and internal surface area will be studied for a series of vitrinite concentrates from some of the major coal measures of the world. The results should throw

light on the chemical nature of coal metamorphism, and the dependence of this on geological conditions.

5. Distribution of aliphatic hydrocarbons associated with coals. The hydrocarbons probably represent the leaf waxes of the original plants; chemical taxonomy may permit correlations with plant type.

(Research sponsored by National Science Foundation.)

MINERAL MATTER IN COAL

Harold J. Gluskoter
Illinois State Geological Survey

The project in this laboratory is related to a wide range of problems pertaining to inorganic constituents of coal, that is, the nature of these constituents, their chemical composition, and states of combination. Studies are being made of these factors and of geological controls on the areal and stratigraphic distribution of mineral constituents.

Successful application of a new technique that permits ashing coal with removal of more than 99 percent of organic matter (at temperatures from 150° to 190° C) is permitting studies of unaltered or only slightly altered mineral constituents in coal. These are identified by chemical, X-ray diffraction, and petrographic methods.

In addition to the general mineral matter studies, special attention is being directed to clay mineralogy of clays in coal, and the forms and distribution of sulfur and chlorine in coal.

<u>Physical Properties of Mineral Matter in Anthracites</u>

P. L. Walker, Jr.
The Pennsylvania State University

Studies have been initiated to learn the effect of temperature and atmosphere on the physical properties of the mineral matter in anthracites. The objective is to obtain data on the physical properties of mineral matter so that the effect of temperature and atmosphere on the physical properties measured on the whole coal can be better understood.

The mineral matter in raw and heat-treated anthracites (heated in inert and oxidizing atmospheres) is separated from the remaining carbon matrix by low-temperature oxidation in an oxygen plasma. Alterations in the mineral matter as it changes to an ash will be followed by infrared spectroscopy, X-ray diffraction, surface area, and density measurements.

A Pennsylvania anthracite will be studied in detail, and a look at the effect of temperature and atmosphere on its mineral matter during heat treatment is also planned.

(Research sponsored by Coal Research Board of the Commonwealth of Pennsylvania.)

MINERALS IN COAL, FLY ASH, AND RELATED MATERIALS

Howard W. Wainwright and Clarence Karr, Jr.
Bureau of Mines

Qualitative and quantitative analyses of various minerals and inorganic compounds in coals and products from carbonization and combustion of coal are being made by nuclear quadrupole resonance spectrometry and infrared spectrometry in the extended (15μ to 50μ) and far (50μ to 600μ) infrared regions.

This work was prompted by need for information on the specific minerals and inorganic compounds in coals, chars, pitches, fly ashes, mine refuse, boiler deposits, and other materials related to coal. For example, little is known about the relationship between the chemical or mineral composition of fly ashes from coal and their collectibility by electrostatic precipitators.

When required, the organic material is removed from the sample, without altering the mineral constituents, by low-temperature (150° to 190° C) ashing with an oxygen plasma in a controlled vacuum.

Analysis by wet chemistry or emission spectrometry gives only the percentages of various metals, arbitrarily recorded as their oxides of highest valence, and not the actual mineral composition. However, nuclear quadrupole resonance and infrared spectrometry have been shown to be highly promising methods for the specific determination of low percentages of various mineral constituents, such as kaolinite, calcite, and quartz.

NUCLEAR METHODS OF ANALYSIS

Robert F. Stewart
Bureau of Mines

The effect of neutrons on coal and materials associated with coal is being determined with the objective of developing new instrumental methods of analysis and control. The magnitude of the various effects and the results of altering physical arrangements and neutron energies are being studied to emphasize or decrease these effects.

The fundamental nature of the work includes (1) the effective diffusion distance of neutrons in materials, particularly coal, (2) the proportion of inelastic gamma rays produced by elemental scattering of neutrons in coal, (3) the proportion of capture gamma rays produced by thermal neutrons, and (4) the shielding properties of various materials for both neutrons and gamma ray attenuation. This basic data is then used for applications such as developing a sulfur meter. The data are used in applied research that includes such areas as satisfactory detector and counting systems, materials handling equipment, and control of physical properties.

This combination of basic research and development is successively improved through empirical testing to obtain adequate relationships. For example, in developing a sulfur meter for coal, the sensitivity of measurement may be limited by interference radiation that is first identified and then reduced by altering materials or neutron energies, or by developing a faster detecting system or a detector of greater resolution.

All methods of continuous nuclear analysis are affected by the bulk density of the test material, a dependence that varies with the basic arrangement Thus, a bulk-density compensator is needed; this instrument requires both basic and applied development. A gamma density gage is "standard" but it is limited in accuracy by the dual attenuation of gamma rays by hydrogen of unknown magnitude. Some method will be sought for determining the significance of this dual attenuation and of correcting or compensating for it by choice of energies, degree of columnation and/or Raleigh scatter, and dual energies, etc. This, in turn, will require knowledge of the effect on bulk density of moisture, particle size, coal type, and other factors.

To solve problems of materials handling, the effect of variables on the shear strength of coal may have to be studied.

OPTICAL PROPERTIES OF COAL COMPONENTS

Sabri Ergun
Bureau of Mines

Optical research is being done in this laboratory on coals and carbon to determine fundamental optical constants of coal components and related carbons particularly graphite. Optical properties serve as an objective basis for description and differentiation of petrographic components of coal and contribute to an understanding of carbon-atom structures in coal and electronic band structure in graphite. A topic of immediate interest is the optical anisotropy of graphite, that is, the variation of optical constants in different directions in this layered structure. Reliable measurements of this characteristic would have application to other layered carbons, such as high-rank coals, and would also contribute to general knowledge of the optics of anisotropic opaque materials.

OXIDATION OF COAL

Irving A. Breger
U.S. Geological Survey

Coal oxidation studies have been made (1) to determine the chemical changes occurring in the coal, (2) to see whether information could be obtained to shed light on the problem of spontaneous combustion of coal, (3) to learn the effects of oxidation on the kerogen constituents related to coal that occur in certain shales, and (4) to obtain information on the proper storage of coal constituents should a maceral bank be established by the International Commission on Coal Petrology.

Coals ranging from high-volatile bituminous to anthracite were oxidized aerially and while submerged in water for periods up to 816 hr, and the data from these experiments are now being evaluated. From these studies, it has already been concluded that coal is best stored when immersed in water at reduced temperatures.

Oxidation of Vitrains

Joseph W. Leonard
West Virginia University

The effects of low-temperature air oxidation on vitrain bands of coal were studied. The coal samples were selected to include those with a wide range of Hardgrove Grindability Index, 50 to 106.5. Photomicrographs of the unoxidized and oxidized coal samples revealed the formation of microfractures (due to oxidation) which changed progressively from a linear form to a conchoidal configuration as time and/or temperature of oxidation increased.

When the oxidized samples were cooled, they showed increases in volatile matter and moisture content, and decreases in fixed carbon, fluidity, calorific value, grindability, and free-swelling index.

OXIDATION OF COAL SULFUR

Hans H. Adler
Atomic Energy Commission

The isotopic characterization of the sulfate from oxidation of sulfides in coal is being investigated under the direction of the U.S. Atomic Energy Commission as part of a program on geochemical reactions influencing uranium deposition. A study of the isotopic composition of coals and their oxidative products is being initiated.

Little is known about the $^{32}S/^{34}S$ composition of coal pyrites and the derivative sulfate that is released in solution as a stream pollutant. The current work on this problem is an adjunct to a broader project on the characterization of waters from many sources and of diverse origins. Hopefully, the characterization of coal in this way will have some application as a tracer technique for studying atmospheric pollution by coal combustion.

The geochemical and bacteriological processes operating during deposition of coals, coalification, and subsequent diagenesis appear not to be much different for the coals of coal deposits and the coalified (subbituminous) organic matter of uranium ore deposits. Of even greater interest are the postmining processes operative on the coals today: For example, aerobic oxidation, which has been accentuated by the exposure of the coalbeds through mining.

The viability of aerobe microbial species in essentially anaerobic marine environment has been advanced as support for the view that oxidation of coal sulfide by aerobes may not require free atmospheric oxygen. Other indications,

however, contradict this opinion. A solution to this question may pave the way for consideration of oxidative processes bearing a uranium emplacement at depths far below the range of atmospheric oxygen incursion. This geochemical problem will be approached by studying the isotopic composition of coals and of their oxidation products.

PALEOBOTANICAL STUDIES

Russell A. Peppers
Illinois State Geological Survey

A continuing program of paleobotanical studies largely (but not exclusively) concerns the stratigraphic distribution of fossil spores and pollen, an aspect of paleobotany referred to as palynology. Efforts are directed toward the examination of Pennsylvania coals and other strata, although older Paleozoic strata are studied as the need arises. Data from such studies are utilized for correlation purposes, and in an overall understanding of the distribution of fossil plants.

One aspect of the work concerns the investigation of botanical entities (other than spores) occurring in coal such as resin rodlets and cuticle. An understanding of this problem is helpful to petrographic investigations of coal. Also, investigations of the fossil plants preserved in coal balls and as compressions are of special interest, when the spore and pollen-producing organs are present, because of the desirability of knowing the affinities of these spores and pollen grains.

The ultimate goal of this research is aimed at an integration of the data so as to obtain as complete a picture as possible about the morphology, paleoecology, and stratigraphic distribution of the fossil plants of Illinois.

PARTICLE TEMPERATURE IN A GAS-SOLIDS SYSTEM

John H. Holden
Bureau of Mines

A procedure for calculating heat transfer for a dilute gas-solids mixture is required for understanding the kinetics of many coal utilization processes. Equations have been formulated and a numerical solution has been developed for heat transfer to a dilute suspension of solids in a gas through an externally heated tube. The calculation procedure will be developed further to evaluate the effects of (1) difference in velocity between the particle and gas, (2) temperature dependence of the convection heat-transfer coefficients, and (3) evolution of volatile matter and the temperature of particles. The goal is to develop a method for calculating heat transfer to particles in a fluidized bed, for use in formulating the kinetics of gasification reactions.

PETROGRAPHIC AND REFLECTANCE STUDIES OF COAL

Automated Microscope

W. F. Berry
Bituminous Coal Research, Inc.

An Ameda (automated microscopic electric data accumulator) microscope has been developed with the cooperation of outside manufacturing firms, for the rapid accumulation of data from petrography of coal by the reflectance technique. This microscope will discriminate and count in size microscopic materials at the rate of 1,000 point counts/sec.

An analysis of a coal sample with the Ameda microscope will give the pyrite-to-coal volumetric relationship as well as the size consist of the pyrite. Future work with the instrument should establish procedures for determining whether pyrite is in a free state, is attached to coal particles, or is encased within the coal. Also, future work should establish procedures for making complete petrographic coal analyses; thus, the analytical time could be reduced from many hours to a few minutes.

The main components of the Ameda microscope consist of (1) a stage drive unit, which is constructed to move the stage and the sample under the microscope objective in a point-count pattern at the speed of 1 mm or 1,000μ/sec; (2) a sensitive photomultiplier head tube, which is operated on a 1,000-Hz alternating current; (3) an effective field of view that is limited to a 1-μ circle so that each signal emanating from the photomultiplier represents a 1-μ circle on the surface of the material being analyzed; and (4) a set of specific pulse counters and computer logic for counting and discriminating each impulse that emanates from the photomultiplier tube.

Correlation of Reflectance Analysis With Utilization

Sabri Ergun
Bureau of Mines

The overall purpose of our coal petrography studies is to maintain a strong degree of competency in knowledge of the physical constitution of coals (characterization of petrographic components) and to investigate the relations of behavior in various utilization processes to petrographic composition. The immediate objectives are (1) to assist in development of standard methods for specimen preparation and visual petrographic analysis, and (2) to develop a rapid, objective method of petrographic analysis, based on reflectance distribution, which will give results amenable to computer analysis and correlation with behavior characteristics. The objective method of reflectance analysis involves microscopic scanning of a molded granular sample of coal, detection of reflected intensity by a photomultiplier, amplification and transmission of the signal to a magnetic tape recorder, and reading the taped information into a computer. The computer program will be devised to test correlations between various parameters, such as reflectance, particle size, petrographic component size, carbon, hydrogen, and oxygen contents, coke stability, and other utilization factors.

Genesis and Utilization Studies

John A. Harrison[5] and Jack A. Simon
Illinois State Geological Survey

The project in this laboratory incorporates a number of related investigations on the quantitative and reflectance analyses of coal, singularly and combined, by using polished surfaces and reflected light procedures. The basic objective is accumulation of factual data relative to coal genesis as well as increased utilization of Illinois coals. Channel and diamond drill core samples are examined petrographically. Other investigations concern the effect of weathering on reflectance, evaluation of nomenclature, concentration of macerals for specific studies, effect of heating on macerals, coal petrography (as related to coking, preparation, combustion, gasification, and hydrogenation), and relationship between rank and reflectance.

For fundamental petrographic investigations, coal pieces (minus 200 mesh) are briquetted with an adhesive and polished on an automatic polisher. These polished samples are examined microscopically for maceral identification and quantity as well as for reflectance characteristics of different macerals from various ranks of coal. Chemical analyses, coking tests, and other related tests are used in conjunction with the accumulated petrographic data, especially for utilization studies.

PROPERTIES OF COAL ESTIMATED FROM STANDARD ANALYSES

Joseph W. Leonard
West Virginia University

The West Virginia Coal Research Bureau has been investigating the correlation of interrelations of the chemical, plastic, thermal, and physical properties of coal by computer studies on data obtained from analyses of more than 400 different coals. Graphical relationships were obtained whereby it is possible to rapidly predict (for quality control purposes) the Hardgrove Grindability Index, Btu value, and the ultimate analysis of a coal from knowledge of the values for the ash, volatile matter, moisture, and induction-furnace sulfur analysis of a given coal.

Other relationships were also established from analytical tests on fractions of coal for mineral matter (MM), volatile matter (VM), and free-swelling index (FSI). These tests can be used to closely estimate the calorific value (Btu), hardness (HGI), Gieseler maximum plastic temperature range (ΔT), and bulk specific gravity (BSG). Relationships of MM versus Btu and MM versus BSG that were developed for distinct petrographic bands permit correlations with other coal properties. Some unexpected relationships have been observed between MM and Btu versus ΔT and between VM and FSI versus HGI.

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[5] Deceased 1967.

PYRITIC SULFUR IN COALS

Sabri Ergun
Bureau of Mines

Automatic optical-electronic scanning equipment and computer analysis will be used to determine the particle size distribution of pyrite, and the association of pyrite with coal particles and different petrographic components. Determinations will be made on both raw and cleaned samples. The experimental program will be as follows: (1) complete testing and determination of optimal operating conditions of the automatic system used for scanning and computer analysis, (2) comparison of selected results of particle size distribution of pyrite that are determined by visual microscopic analysis and by automatic scanning, (3) development of computer programs for determining (from scanning data) the mode of association of pyrite particles with coal particles and petrographic components, (4) comprehensive studies of the pyrite in raw and cleaned samples of typical steam coals and coals representative of various coalfields and states, and (5) correlation of the size and distribution data of pyrite with washability studies.

PYROLYSIS OF COAL

George Richard Hill, Wendell H. Wiser, and Larry L. Anderson
University of Utah

Pyrolysis studies in this laboratory involve raising the temperature of the coal as rapidly as possible to a predetermined temperature, then holding the temperature constant throughout the period of study and observing the rate of product evolution as a function of time at constant temperature. The progress of the pyrolysis reactions are followed by observing the decrease in weight of the sample as a function of time. Earlier studies utilized a quartz spring; current studies utilize a Cahn electrobalance equipped with a recorder. The evolved products have been analyzed by mass spectrometry, gas chromatography, infrared and ultraviolet spectrophotometry, and other techniques. The data thus obtained have been applied to kinetic expressions in an effort to understand the basic mechanisms involved in coal pyrolysis.

Inasmuch as coal is an extremely complex substance, many reactions are involved. The process involves consecutive reactions as well as competing reactions. Undoubtedly, the products that finally evolve from the coal are not the primary products formed in the thermal decomposition of the original coal structure. Although some investigators have regarded the application of kinetic expressions to this overall complex process as not too meaningful, such application has been made in this laboratory owing to some national interest in production of liquid or gaseous fuels from coal. Such commercial application will involve the overall complex process and it is of interest to try to understand the parameters associated with the rate-determining steps in the overall process.

A careful examination of the pyrolysis data and application of the kinetic expressions reveals that the slow and rate-determining step in the

overall pyrolysis process is second order throughout most of the product evolution. As chemical reactions give way to physical processes in importance in the process, the order of the reaction changes to first order; however, the majority of the product evolution occurs under second-order conditions.

Studies have been made that relate the process of coal pyrolysis to the process of dissolution of coal in tetralin. These two processes have been observed to be very similar in nature. Both processes are believed to involve an initial and extensive thermal bond rupture in the coal structure. The extent of product evolution or product solubility in the solvent is then determined by the nature and quantity of available atoms or radicals for stabilization of the radicals formed in the thermal decomposition process. This part of the process represents a competition between polymerization to produce large "molecules" and stabilization to form smaller "molecules."

Studies involving catalytic hydrogenation of coal in a batch operation lend further support to this model for coal pyrolysis. This work is currently in progress and is described briefly in the section entitled Hydrogenation of Coal and Coal Tar.

Current pyrolysis studies in this laboratory involve an effort to obtain greater accuracy in the short-time region, particularly in the first 10 minutes of pyrolysis. Studies contemplated for the future involve parallel investigations using rapid heating techniques wherein the coal particles remain separated, and also the more conventional slower heating techniques wherein the coal particles may fuse together. Studies are also contemplated wherein very small coal particles will be raised rapidly to the pyrolysis temperature (for example, 450° C), and the initial products will be examined as they escape from the surface of the small particle. Various techniques (laser bombardment, microwave radiation, etc.) will be used to rapidly increase the particle temperature. These techniques should yield information concerning the primary products in coal pyrolysis.

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PYROLYSIS OF COAL IN A HIGH-INTENSITY ARC

Val J. Krukonis
Avco Corporation

A program now being carried out concerns the demonstration of an economic process for producing acetylene from coal. In the process under study, coal is being reacted as a consumable anode in a high-intensity arc.

The use of consumable anodes in high-intensity arc reactions has been described in the literature. For example, submicron particles of refractory metals have been produced by striking an arc to an anode made of the metal. It has been shown that the energy efficiency, that is, the fraction of electrical energy transferred to the anode, is very high. For example, 70 to 90 percent of the power can be dissipated in a zone at or near the anode surface

(called the anode fall space). A plasma jet device, which has been used for rapid coal pyrolysis, is a relatively inefficient method of heating a solid, because typically only 50 to 60 percent of the electrical energy is transferred to a gas that subsequently must transfer heat to solid particles.

In our work, an electric discharge is sustained between a graphite cathode and coal, which is the anode of the electrical circuit. Crushed coal, typically -8+18 mesh, is fed through a tube to the surface where the high-energy flux very rapidly decomposes the coal into gaseous products. Part of the solid residue is swept away as fine particles with the gases; the remainder falls to the bottom of the reactor in larger agglomerated form. The hot gas stream is quenched downstream of the electrical discharge in order to stabilize the acetylene produced.

When an inert quench was used, the products formed only from the arc-coal interaction could be determined, although reactions both at the solid surface and in the gas phase probably occurred. The results from using an argon quench were similar to those obtained in other rapid pyrolysis work; that is, the yield of acetylene was higher than obtained during slow carbonization. Yields of 4 to 5 percent based on total coal were obtained, but they were not as high as the values of 15 to 20 percent demonstrated in the plasma jet work. However, the specific energy requirement was lower, a result of more efficient energy transfer to the coal. Values of 30 to 40 kwhr/lb C_2H_2 were obtained in these experiments. Even these values, however, are not economic, because a preliminary analysis has indicated that a process producing acetylene from coal at 5 kwhr/lb would be competitive with existing acetylene processes.

The use of a hydrogen quench markedly enhanced the yields of acetylene. Yields of 10 to 11 percent were obtained, and the specific energy requirement with a hydrogen quench decreased to 14 to 15 kwhr/lb C_2H_2. Studies are now in progress to determine the mechanisms that give higher yields of acetylene when hydrogen quench is used.

The emphasis of the program is on increasing the yield of acetylene and the energy efficiency of the reaction. Specifically, investigations of the effects of such parameters as anode-cathode geometry, power-to-coal-feed ratio, and mode of quenching will be carried out. For example, some recent measurements have shown that a substantial amount of energy is being transferred directly to the coal feed tube. This energy, therefore, is unavailable for pyrolyzing coal. Several alternative anode-cathode configurations that may eliminate this energy loss are being considered. Optimum power-to-feed ratios still have not been attained. For example, high yields can be achieved as was shown in the plasma jet work, but in those experiments the power-to-feed ratio was high, and consequently, energy utilization was low. In order to achieve economic feasibility, it is more important to optimize energy utilization.

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RADIOCHEMICAL ANALYSIS

Rodney R. Ruch
Illinois State Geological Survey

A comprehensive investigation of neutron activation methods of analysis for geologic materials is in progress. A large number of trace metals, rare earths, and certain major constituents are being studied in silicate rocks, sediments, minerals, crude oil, coal, and brine.

Four areas of research are included:

1. Instrumental Approach. A survey of those elements that can readily be determined by neutron activation methods without chemical treatment of samples is being made.

2. Radiochemical Separation. Chemical procedures involving sample dissolution, distillation, and ion exchange are being used to separate 14 trace elements from geologic materials in an effort to increase sensitivity and reduce interferences. These methods are being applied to elements that are not readily determined by the instrumental approach.

3. Gamma-Gamma Coincidence Counting. Evaluation of gamma-gamma coincidence counting is being made for the determination of chlorine in raw coal at the <0.01 percent level.

4. Mixed Amalgam Exchange. A different approach to radiochemical separations is being studied for determination of Zn, In, Cd, Sn, and Hg in geologic materials. An amalgam composed of several soluble, nonradioactive metals is agitated with a dissolved, irradiated sample containing the corresponding radioactive metal salts. The desired radioactivity exchanges into the amalgam phase and is counted.

RATES OF GASIFICATION OF COALS AND CHARS

George A. Brady
Bureau of Mines

The Bureau of Mines plans to study the rates of the gasification of different coals (and chars made from these coals) in a steam-fluidized bed. Included in this study will be the overall effects of chemical reaction rates mass and heat transfer from gas to particle, and the average overall effect of burn-off. The role of ash buildup, actual size distribution of particles in the bed, catalytic effects of ash, and gas composition of the bed will be investigated.

REACTIONS OF COAL AND COAL DERIVATIVES IN A CORONA DISCHARGE

T. C. Ruppel and Daniel Bienstock
Bureau of Mines

The reactions of coal and coal-derived products in a corona discharge are being investigated with the view of converting coal into potentially marketable compounds. At first, simple systems such as mixtures of carbon monoxide, carbon dioxide, hydrogen, nitrogen, and steam were studied to gain an understanding of the effects of selected process variables on product characteristics. In the presence of a corona discharge, the following reactions occur: air yields nitrogen oxides; CO_2 yields $CO + O_2$; $H_2O + CO$ is partially converted to $H_2 + CO_2$ (the reverse reaction also occurs); and $H_2 + CO_2 + N_2$ produces H_2O, CO, NH_3, NH_4HCO_3, and nitrogen oxides.

The results of these studies indicate that generally product yield (1) increases with pressure, temperature, and power input, (2) decreases with space velocity, (3) is unaffected by ac frequency up to 15,000 Hz, surface-to-volume ratio of reactor, and static or dynamic nature of the system, and (4) is practically zero in the absence of a discharge.

At present, crushed coal is being subjected to a corona discharge. We plan to determine the effect of reactor temperature, particle size of coal, type of feed gas, and gas-flow rate upon the composition of the gaseous effluent for fixed, fluidized, and falling beds.

REACTIONS OF COAL WITH REACTIVE SPECIES IN ELECTRICAL DISCHARGES

Bernard D. Blaustein, Yuan C. Fu, and Irving Wender
Bureau of Mines

The effects of microwave-generated gas discharges on various coals and model substances are being investigated. This work is part of a program to learn more about the chemistry of coal and to develop novel uses for coal. Acetylene accounts for 75 to 95 volume-percent of the gaseous hydrocarbons produced in all the discharges studied, and except for lignite, the yield of hydrocarbons increases with increasing volatile matter content of the coal.

Reactions of coal in microwave discharges in hydrogen, water vapor, and argon have been studied. Microwave discharges in mixtures of (H_2 + CO) and ($H_2 + CO_2$) also have been studied.

Coal is partially gasified to give gaseous hydrocarbons and carbon oxides as well as a tar and residual char. Hydrogen also is produced either by dissociation of H_2O or by devolatilization of the coal in the H_2O and/or Ar discharge. But in the H_2 discharge, hydrogen is mostly consumed rather than produced (except for hvab coal and lignite). Gasification of coal in the H_2O discharge is especially interesting because the reaction produces substantial amounts of acetylene and methane as well as hydrogen and carbon monoxide.

The reactions of (H_2 + CO) and (H_2 + CO_2) mixtures in microwave discharges at initial gas pressures of 12±1 torr gave conversions of CO to (CH_4 + C_2H_2) at 17 to 18 volume-percent for reaction times of 30 to 120 sec; experiments at 50±3 torr gave conversions of 24 to 25 percent for reaction times of 3 to 4 min. When water is added to the initial reactant mixture, the formation of hydrocarbons is strongly repressed. The conversion of carbon monoxide is increased by removing the reaction products as they form. This can be done by surrounding the bottom of the reactor with a cold trap before and during the time the discharge is on. When the discharge was maintained for 3 minutes while the end of the reactor was at -78° C, 78 percent of the carbon monoxide was converted to hydrocarbons, mostly methane. At -196° C, 90 percent of the carbon monoxide reacted to form mostly C_2H_6 and C_2H_2. The different conversions of carbon monoxide under these conditions can be explained by assuming that the reaction in the discharge when the bottom of the reactor is not cooled reaches a stationary state or pseudoequilibrium in which production of hydrocarbons is limited by their back reaction with H_2O and/or CO_2 to form H_2 + CO.

Vacuum pyrolysis of coal under the influence of a microwave discharge is being studied. As in thermal pyrolysis of coal, hydrogen, carbon monoxide, and hydrocarbons are obtained for the electric-discharge pyrolysis of coal; however, acetylene, in addition to methane, is a major constituent of the hydrocarbons. In the discharge pyrolysis of coal, the gases evolving at various states of the devolatilization contain nearly constant concentrations of acetylene and methane, except perhaps at later stages of the devolatilization. The concentration of hydrogen increases and carbon monoxide decreases with the progress of the gasification of the carbon in coal.

The reactions of mixtures of hydrogen, carbon monoxide, and nitrogen will be studied. Preliminary results indicate that about 30 volume-percent of the carbon monoxide is converted to HCN and 3 percent is converted to methane; trace amounts of acetylene also are formed.

ROAD BINDERS FROM HYDROGENATION OF COAL

H. F. Silver
University of Wyoming

The feasibility of using hydrogenated coal bitumen as a road binder is being studied. Laboratory evaluations indicate that a hydrogenated coal bitumen with properties similar to those of asphalts and road tars can be produced.

Hydrogenated coal bitumen has been obtained in good yield from coal. The yield and properties of the bitumen depend on the reaction conditions, the coal, and the solvent used. Low-rank coals, such as those found in Wyoming, appear the most reactive. Solvents similar to those used in coal hydrogenation seem effective.

Results from laboratory studies of samples weighing 20 g or less indicate the desirability of producing larger samples for more extensive evaluation.

SOIL CONDITIONERS AND FERTILIZERS FROM LIGNITES

James L. Elder
Bureau of Mines

Lignite and leonardite, a naturally oxidized lignite, are being investigated for the preparation of soil conditioners and fertilizers. Bench-scale and field studies are directed to understanding the principles involved in growth improvement and amelioration of soil structure by lignite coal and the humic acids derived therefrom.

SORPTION OF METHANE ON COAL

T. C. Ruppel and Daniel Bienstock
Bureau of Mines

Adsorption and desorption isotherms of methane on several U.S. coals are being studied in the pressure range of 1 to 150 atm and in the temperature range of 0° to 50° C. These include the ranges found in coal mines. Few equilibrium sorption data are available on U.S. coals in contrast with the extensive data on British and Russian coals. The objective of this work is to relate the data to the storage and release of methane in coal mines and to obtain fundamental knowledge that ultimately can be used for obtaining optimal methods of (underground mine) degasification.

Results at atmospheric pressure indicate that with +6-325 mesh coal the rate of attainment of equilibrium increases exponentially with particle size, whereas the quantity of methane adsorbed at equilibrium is independent of particle size.

The results of this study will provide a better knowledge of the methane-storage capacity of U.S. coals.

SPECTROMETRY OF COAL

R. A. Friedel and A. G. Sharkey, Jr.
Bureau of Mines

Spectral techniques offer powerful means of investigating certain properties of coal, because each technique almost uniquely reveals specific information.

Electron paramagnetic resonance (EPR) spectrometry is a means of studying materials that possess unpaired electrons. All coals give EPR signals; the absorption is generally attributed to the presence of free radicals in the coal. Other species such as charge-transfer complexes, however, may contribute to or be totally responsible for the EPR absorption. Variable temperature studies are planned to investigate the nature of the paramagnetic species in coal because the temperature dependence of EPR-signal intensities often can be related to specific types of paramagnetic species. Coals, coal macerals, charge-transfer complexes of coal, and coals with adsorbed species will be

investigated. A few humic acids and laser-irradiated coal also will be examined. A study of radical ions of hydroaromatic compounds will be initiated because these may serve as model systems for the paramagnetic species in coal

Infrared spectrometric studies of coals and low-temperature chars in thi laboratory have revealed the similarity of these materials. This similarity has been utilized by preparing chars for spectral studies from chemically treated and isotope-labeled starting materials. ^{18}O-labeled chars were used to search for the presence of chelated carbonyls. Another approach to the question of carbonyls in coal, now nearing completion, is a survey of absorption intensities for carbonyl compounds and correlation of these intensities with those found in the spectra of coals.

Nuclear magnetic resonance (NMR) studies have given much valuable information concerning the distribution of hydrogen and carbon atoms in coal and materials derived from coal. These studies will continue with particular emphasis on the application of time-averaging to high-resolution carbon-13 NM spectral investigations. Highly precise values for the aromaticity of liquid products and soluble materials from coal will be obtained utilizing this tech nique. Studies of coal, pure compounds of simple molecular structure, and selectively enriched (^{13}C) pure compounds in the solid state by ^{13}C NMR will also be made. These latter experiments will be pioneering in nature and will also require the use of spectral time-averaging.

Ultraviolet-visible spectrometry has been used to determine optical constants of coals, to calculate limits for the polynuclear aromaticity of coal, and, most recently, to explain the various colors transmitted by thin sectior of coal having different thickness. In work now in progress ultraviolet-visible spectrometry is being used in conjunction with other spectral techniques to study charge-transfer characteristics of coals and coal derivatives and to study free radicals, aromaticity, and scattering phenomena in coals.

New Spectral Techniques for Coal Research

R. A. Friedel and A. G. Sharkey, Jr.
Bureau of Mines

New spectrometric techniques that appear adaptable to coal research wil be evaluated. The following five investigations have been initiated or are planned:

1. Use of a time-of-flight mass spectrometer to detect species importa in high-temperature coal combustion and air-pollution studies is being investigated.

2. Combined gas chromatographic-mass spectrometric techniques will be developed to detect trace constituents in coal derivatives. A detailed comparison will be made of mine gas and natural gas by this technique; the difference in these gases is not well documented at present. New automatic dat processing methods and equipment that have applicability to spectral data wi be investigated. Techniques for analyzing hydroaromatic compounds important

in many coal research projects will be developed by using an unheated probe with a high-resolution mass spectrometer.

3. The first measurements of NMR relaxation times in a coal were obtained for this laboratory through the courtesy of a manufacturer of pulsed NMR spectrometers. The very short times found for proton relaxation through both the mechanisms of spin-lattice and spin-spin relaxation indicate that "lifetime" broadening of the spectral lines, obtained by steady state methods, is occurring. Probably, the relaxation processes are promoted by the presence of paramagnetic species in the coal. The technique will be applied to several coals of different ranks, coal extracts, and to coals at other than room temperature.

4. The nondestructive Mössbauer nuclear resonance spectral method for the study of iron is being applied to petrographic components of coals ranging from lignite to anthracite, in order to determine in situ the types of iron compounds, or to determine the valencies of the types of iron and the degree of symmetry of the structure surrounding the iron atoms. For those coals in which the iron content is too low for observation, the iron, along with all other minerals, is being concentrated by oxidizing the coals at low temperatures. The organic matter is decreased by this method without producing changes in the minerals.

For those coals in which iron structures are not identifiable, heat treatment of various temperatures and chemical treatments will be utilized; Mössbauer spectra will be obtained before and after.

5. Results by electron microprobe analyzer will be correlated with Mössbauer spectra. Element maps obtained on the microprobe will establish the identity of elements nearest to the iron atoms, and thus may indicate whether the iron is bound to organic or inorganic structures.

STRUCTURAL CHEMISTRY OF SOIL HUMIC SUBSTANCES

F. J. Stevenson
University of Illinois

The structural arrangement of oxygen functional groups in humic and fulvic acids is being studied by infrared and functional-group techniques. Environmental factors influencing the ratio of carboxyl to acidic hydroxyl (phenolic hydroxyl?) groups are being investigated. Other problems under consideration include (1) origin of the 1,600 cm^{-1} band in the infrared spectrum, (2) occurrence of quinone linkages, H-bonded hydroxyl groups, and free amino groups, and (3) genetic relationship between fulvic acids, humic acids, and other similar natural products.

SULFUR IN COAL

Coal Preparation

Jack A. Simon, Roy J. Helfinstine, and Neil F. Shimp
Illinois State Geological Survey

A comprehensive program is in progress to evaluate the preparation and other characteristics of Illinois coals, with particular emphasis on forms and distribution of sulfur. In the initial phase of the project, a minimum of 30 mines, widely distributed geographically and inclusive of all currently mined coals, has been selected.

Basic samples consist of tipple samples obtained incrementally through one shift of output plus at least three face channel samples from each mine. Extensive float-sink separations and comprehensive chemical analyses are being made on these samples.

Although a substantial amount of the data are fundamental to many of our research needs, data to be developed will be applicable to improved evaluation of potential pyritic-sulfur removal for Illinois coals, and a basis for evaluation of pyrite content of coal mine refuse.

These calculations are basic to the assessments of the possible reduction of sulfur in coal for combustion uses, the possible reduction in sulfur content to enlarge the percentage of coal reserves that might have use in blending for metallurgical coke, the possible reduction of sulfur in mine refuse in order to minimize stream pollution problems, and the determination of the potential for concentration of pyrite from Illinois coals as a raw material for sulfur recovery.

Relation to Geological Conditions

M. E. Hopkins
Illinois State Geological Survey

This study is part of a continuing project that is intended to delineate a large area of relatively low-sulfur No. 5 coal in Southeastern Illinois. Experience has shown that the sulfur content of coal is related to the nature of the overlying roof strata and that the variations and character of the roof strata can be mapped from electric logs of oil tests. The electric logs were carefully compared with core descriptions from nearby diamond drill holes in part of the area. It was found that relatively accurate estimations of coal thicknesses could be made from these electric logs. From this area, the data have been extended into the deeper part of the Illinois Basin where the only available information is from oil tests.

From this study, in addition to adding to the resources inventory of coal in Illinois, it is hoped that (1) our knowledge on the relations of sulfur in coal to geologic conditions will be increased; and (2) our ability to use electrical resistivity logs of oil tests (of which there are some 70,000 on file at the Illinois State Geological Survey) will be increased.

Retention in Anthracite Ash

J. J. Demeter and Daniel Bienstock
Bureau of Mines

Anthracite from the four producing regions of Pennsylvania was ashed in he laboratory and also burned in a chain-grate stoker to determine the sulfur-etention properties of its ash. The retention of sulfur in anthracite ash repared in the laboratory was found related to ashing temperature and to mounts of sulfur and calcium present in the coal. At the usual laboratory shing temperature of 750° C, sulfur retention ranged from 0.6 to 13.2 percent, hile the sulfur-retention capacity of the calcium ranged from 5.7 to 30.9 ercent. The sulfur retained in the ash declines progressively with tempera-ure. At 1,200° C, the sulfur retained in the ash was negligible, that is, 0 o 0.3 percent. Since combustion temperatures involved in most commercial pplications are above 1,200° C, the thermal decomposition temperature of cal-ium sulfate, this compound does not form and hence cannot serve as a sulfur-etaining agent.

The high-temperature combustion tests on the chain-grate stoker substan-iated the conclusions drawn from the laboratory ashing tests. Neither the alcium nor any other inorganic component of the ash had any effect upon the mount of sulfur retained in the ash. The percentage of sulfur retained in he ash was, however, related to and slightly less than the percentage of the riginal carbon in the coal remaining in the ash. Since the unburned carbon n the ash requires combustion of additional coal to achieve the necessary eat output, the net effect of the increased coal consumption would be ncreased sulfur emission.

Retention in Bituminous Coal Ash

Orin W. Rees and Neil F. Shimp
Illinois State Geological Survey

A study of the mechanism by which sulfur is retained in coal ash is being onducted. It is known that during coal combustion, sulfur is retained in ash s $CaSO_4$. The quantity retained is affected by the calcium content; however, he relationship is not yet definitive. The objective of this study is to nvestigate possible catalytic effects of other constituents on sulfur reten-ion in coal ash.

SULFUR MODES IN COAL

Clarence Karr, Jr.
Bureau of Mines

The nature of the sulfur compounds in coal is being studied. Recent nvestigations indicate that wide-line nuclear magnetic resonance spectroscopy ot only would be a rapid, unique method for characterizing the various ways ulfur occurs in coal but also would be far more specific than currently used ethods. Specific information about mode of occurrence should allow a

rational approach to new methods of removing sulfur from coal before combustion. Coal, therefore, could be used as a source of energy without polluting the atmosphere.

SURFACE AREAS OF COALS

Josephus Thomas, Jr.
Illinois State Geological Survey

Studies of the internal surface areas of coals are being conducted by use of dynamic-sorption apparatus with carbon dioxide as the adsorbate. Thermal conductivity cells are being used for detecting and measuring the gas volumes adsorbed and desorbed.

Comparison studies of the dynamic method with carbon dioxide at 195° K versus static methods with nitrogen at 77° K were made on various coals. More realistic surface area values are obtained by the dynamic method, which provides a sharper differentiation between coals. The dynamic method is also more amenable to routine operation.

Internal surface area determinations have been assessed relative to coal petrography, that is, reflectance of vitrinite and petrographic composition.

ULTRASONIC IRRADIATION OF COAL AND COAL PRODUCTS

R. A. Friedel and A. G. Sharkey, Jr.
Bureau of Mines

The ultrasonic irradiation of coal and coal products is being studied to determine (1) what new organic compounds, or high concentration of a particular organic species, can be formed by exposure to ultrasonic irradiation; and (2) if the solvation of coal in organic solvents can be markedly increased by ultrasonic irradiation.

The ultrasonic irradiation (sonolysis) of coal derivatives and of coal is important for the production of greater yields of extracts; thus, coal structural studies on such extracts would have greater significance. The method has been found useful also in producing new organic compounds from irradiation of coal derivatives and model compounds. Previous work in this field has been done in aqueous solutions and therefore has dealt primarily with compounds soluble in water. Our experiments have shown for the first time that the presence of water is unnecessary and that sonolysis can bring about decomposition in an organic phase.

Coal is highly soluble in tetralin at about 300° C. Hydrogen transfer from the solvent to the coal is regarded as the mechanism by which increased solubility takes place. Because evidence exists that ultrasonic irradiation will rupture carbon-hydrogen and carbon-carbon bonds, hydrogen transfer very likely can be promoted in organic solvent coal slurries by ultrasonic irradiation at room temperature.

Increased solubility of coals reduced by lithium-ethylenediamine has been reported by the chemistry laboratory of the Pittsburgh Coal Research Center. Pyridine extracts of Pittsburgh seam vitrain obtained before and after reduction were investigated by high-resolution mass spectrometry. Support was obtained for the theories advanced by Reggel and others[6] for the greater solubility of the reduced coals. The mass spectra indicated (1) the formation of hydroaromatic compounds, (2) an increase in volatile oxygenated compounds, possibly from splitting of ether linkages in coal, and (3) the elimination of sulfur in the reduced coal.

UPGRADING MIXED ACIDS FROM COAL OXIDATION

Sidney Friedman and Irving Wender
Bureau of Mines

A method is being developed for converting mixtures of polycarboxylic aromatic acids (from coal oxidation) into industrially useful acids such as isophthalic and terephthalic acids.

One of the few reactions that has been investigated for the purpose of converting coal directly to chemicals is controlled oxidation. This process usually involves oxidation by either nitric acid or oxygen and base. The resulting product may contain more than 50 percent of the original carbon as mixed aromatic polycarboxylic acids. Coal oxidation has been explored by many investigators, but the processes did not attain commercialization because the resulting mixed aromatic acids lacked marketability.

A recent discovery at the Bureau of Mines may change the unfavorable outlook for coal as a source of chemicals. Initially, it was found that phthalic anhydride was converted quantitatively into benzoic acid by heating the anhydride to 200° C in the presence of $Co_2(CO)_8$ and under pressure with hydrogen and carbon monoxide. This process contrasts with other decarboxylation procedures that yield only benzene from phthalic anhydride or acid. Further experiments established that benzene polycarboxylic acids up to mellitic acid (benzenehexacarboxylic acid) could be selectively decarboxylated by this new method to yield principally iso- and terephthalic acids.

This decarboxylation provides a way for converting the previously mentioned complex mixture of aromatic polycarboxylic acids into a simpler mixture containing large and recoverable amounts of industrially valuable isophthalic and terephthalic acids.

Work is in progress on improving catalyst performance by use of metal carbonyls containing various ligands. Future work will include (1) studies on the use of cheaper solvents for the recovery of the acids (dioxane is now used), and (2) refinement of the experimental details to obtain optimum yields of benzene polycarboxylic acids from the oxidation of coal.

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[6]Reggel, L., R. Raymond, W. A. Steiner, R. A. Friedel, and I. Wender. Reduction of Coal by Lithium-Ethylenediamine. Studies on a Series of Vitrains. Fuel, v. 40, 1961, pp. 339-356.

X-RAY DIFFRACTION OF COAL, COKE, AND CARBONS

Sabri Ergun
Bureau of Mines

The objective of the X-ray diffraction research in this laboratory is to investigate atomic and molecular structures in coals, cokes, and carbons. Two phases of this research now being emphasized are (1) the development and refinement of radial distribution analysis of X-ray scattering at moderately high angles to obtain atomic spacings and atomic densities, and (2) low-angle scattering studies to obtain information about sizes of pores or atom-layer clusters in coals, cokes, and other carbons. Information obtained in the first phase should contribute to knowledge of the basic atomic structures in these materials; that from the second phase may be helpful in characterizing the physical properties of cokes and other carbons.

X-RAY FLUORESCENCE ANALYSIS

Neil F. Shimp
Illinois State Geological Survey

Application of quantitative X-ray fluorescence methods for determination of major, minor, and trace constituents in silicate rocks, minerals, coals, and coal ashes is being investigated. For many elements, the method is much more rapid than conventional methods; for certain elements, better sensitivity can be achieved. Analyses currently under consideration include major elements normally determined in silicate rocks, zinc in argillaceous sediments, and chlorine and sulfur in raw coal. In addition, it is planned to apply X-ray fluorescence methods to the determination of certain inorganic constituents in raw coal, for example, alumina, silica, and iron.

ZETA POTENTIAL IN COAL-PYRITE SEPARATION

Albert W. Deurbrouck
Bureau of Mines

The importance of zeta-potential control in coal preparation is now being examined with the objective of improving or developing methods to reduce the pyritic-sulfur content of fine coal.

Froth Flotation

Zeta-potential measurements in conjunction with Hallimond-tube flotation tests have shown a correlation between zeta potential and the floatability of coal and pyrite. For example, when calcium hydroxide, a pyrite depressant frequently used by the minerals industry, was added cumulatively to a coal-pyrite slurry, the zeta potential of the particles changed gradually from negative to highly positive while their float recovery was reduced. No other calcium compounds (nor any other tested divalent cationic reagents) were this effective as flotation depressants; correspondingly, they had no effect on zeta potential beyond reducing it to the isoelectric point. However,

trivalent cationic reagents (such as ferric chloride, ferric sulfate, aluminum chloride, and aluminum sulfate) when precipitated as insoluble hydroxides or oxides gave essentially the same results as calcium hydroxide, and they had a similar effect on zeta potential. Further, these reagents were effective at dosage levels as low as one-fiftieth that of calcium hydroxide.

Electrokinetic Separation

As indicated by zeta-potential analyses of coal and pyrite particles in aqueous suspension, precipitated aluminum hydroxide adsorbs more selectively on pyrite than on coal, whereas precipitated ferric hydroxide absorbs more selectively on coal. Further tests with these reagents, especially the aluminum compound, have shown that coal and pyrite particles can be charged oppositely and, thereby, be caused to migrate toward opposite electrodes simultaneously. This is the basis for our present work in developing a laboratory, electrophoresis cell for the electrokinetic separation of coal and pyrite.

Future work will include the use of cationic and anionic collector-frothers for the selective flotation of coal or pyrite. Also, a miniature, froth-flotation cell (capacity 100 ml) and bench-scale froth-flotation equipment will be employed to test the most promising trends observed in the Hallimond tube.

AUTHOR AND ADDRESS DIRECTORY

Dr. Hans H. Adler
Division of Raw Materials
U.S. Atomic Energy Commission
Washington, D.C. 20545

Dr. Larry L. Anderson
Department of Fuels Engineering
University of Utah
Salt Lake City, Utah 84112

Dr. Herbert M. Appell
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

L. D. Arnold
Illinois State Geological Survey
Natural Resources Building
Urbana, Ill. 61801

Dr. L. G. Austin
Department of Chemical Engineering
North Carolina State University
at Raleigh
N.C. 27607

Charles W. Beeler
Illinois State Geological Survey
Natural Resource Building
Urbana, Ill. 61801

Dr. Lloyd Berg
Department of Chemical Engineering
Montana State University
Bozeman, Mont. 59715

Dr. W. F. Berry
Bituminous Coal Research, Inc.
Monroeville, Pa. 15146

Daniel Bienstock
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

Dr. Bernard D. Blaustein
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

George A. Brady
Morgantown Coal Research Center
Bureau of Mines
Morgantown, W. Va. 26505

Dr. Irving A. Breger
Geochemist
U.S. Geological Survey
Washington, D.C. 20240

Dr. L. E. Casida
Department of Microbiology
The Pennsylvania State University
University Park, Pa. 16802

Dr. Tsaihwa J. Chow
Scripps Institution of Oceanography
La Jolla, Calif. 92038

J. J. Demeter
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

Albert W. Deurbrouck
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

John L. Earl
Scripps Institution of Oceanography
La Jolla, Calif. 92038

James L. Elder, Chief
Grand Forks Coal Research Laboratory
Bureau of Mines
Grand Forks, N. Dak. 58201

Dr. Sabri Ergun
Pittsburgh Coal Research
Bureau of Mines
Pittsburgh, Pa. 15213

Dr. Robert H. Essenhigh
College of Earth and Mineral
Sciences
The Pennsylvania State University
University Park, Pa. 16802

Joseph H. Field
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

Dr. R. A. Friedel
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

Dr. Sidney Friedman
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

Dr. Yuan C. Fu
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

Dr. R. P. Gardner
Department of Chemical Engineering
North Carolina State University
at Raleigh
N.C. 27607

Dr. P. H. Given
College of Earth and Mineral Sciences
The Pennsylvania State University
University Park, Pa. 16802

Dr. Harold J. Gluskoter
Illinois State Geological Survey
Natural Resources Building
Urbana, Ill. 61801

Roy J. Helfinstine
Illinois State Geological Survey
Natural Resources Building
Urbana, Ill. 61801

Dr. George Richard Hill, Dean
College of Mines and Mineral
Industries
University of Utah
Salt Lake City, Utah 84112

Raymond W. Hiteshue
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

John H. Holden
Morgantown Coal Research Center
Bureau of Mines
Morgantown, W. Va. 26505

Dr. M. E. Hopkins
Illinois State Geological Survey
Natural Resources Building
Urbana, Ill. 61801

Harold W. Jackman
Illinois State Geological Survey
Natural Resources Building
Urbana, Ill. 61801

Dr. Clarence Karr, Jr.
Morgantown Coal Research Center
Bureau of Mines
Morgantown, W. Va. 26505

Dr. Val J. Krukonis
Avco Corporation
Space Systems Division
Lowell Industrial Park
Lowell, Mass. 01851

John K. Kuhn
Illinois State Geological Survey
Natural Resources Building
Urbana, Ill. 61801

Joseph W. Leonard, Director
Coal Research Bureau
West Virginia University
Morgantown, W. Va. 26506

R. G. Moses
Bituminous Coal Research, Inc.
Monroeville, Pa. 15146

Dr. A. A. Orning
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

Dr. Russell A. Peppers
Illinois State Geological Survey
Natural Resources Survey
Urbana, Ill. 61801

Dr. Allen H. Pulsifer
Department of Chemical Engineering
Iowa State University of Science
and Technology
Ames, Iowa 50010

Carl Rampacek, Research Director
College Park Metallurgy Research
Center
Bureau of Mines
College Park, Md. 20740

Dr. Orin W. Rees
Illinois State Geological Survey
Natural Resources Building
Urbana, Ill. 61801

Dr. Leslie Reggel
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

Dr. Rodney R. Ruch
Illinois State Geological Survey
Natural Resources Building
Urbana, Ill. 61801

T. C. Ruppel
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

Dr. Harold Shalit
ARCO Chemical Company
Division of Atlantic Richfield
Company
Glenolden, Pa. 19036

A. G. Sharkey, Jr.
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

Dr. Neil F. Shimp
Illinois State Geological Survey
Natural Resources Building
Urbana, Ill. 61801

Dr. H. F. Silver
College of Engineering
The University of Wyoming
Laramie, Wyo. 82070

Jack A. Simon
Illinois State Geological Survey
Natural Resources Building
Urbana, Ill. 61801

Dr. William Spackman
College of Earth and Mineral
Sciences
The Pennsylvania State University
University Park, Pa. 16802

Dr. Heinz W. Sternberg
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

Dr. F. J. Stevenson
Department of Agronomy
University of Illinois
Urbana, Ill. 61801

Robert F. Stewart
Morgantown Coal Research Center
Bureau of Mines
Morgantown, W. Va. 26505

Dr. F. M. Swain
Department of Geology and Geophysic
University of Minnesota
Minneapolis, Minn. 55455

Dr. Josephus Thomas, Jr.
Illinois State Geological Survey
Natural Resources Building
Urbana, Ill. 61801

Dr. F. J. Vastola
College of Earth and Mineral
Sciences
The Pennsylvania State University
University Park, Pa. 16802

Harold W. Wainwright
Morgantown Coal Research Center
Bureau of Mines
Morgantown, W. Va. 26505

Dr. P. L. Walker, Jr.
College of Earth and Mineral
Sciences
The Pennsylvania State University
University Park, Pa. 16802

Dr. Irving Wender
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

Dr. Thomas D. Wheelock
Department of Chemical Engineering
Iowa State University of Science
and Technology
Ames, Iowa 50010

Dr. Wendell H. Wiser, Chairman
Department of Fuels Engineering
University of Utah
Salt Lake City, Utah 84112

David E. Wolfson
Pittsburgh Coal Research Center
Bureau of Mines
Pittsburgh, Pa. 15213

Peter Zubovic
U.S. Geological Survey
Washington, D.C. 20242

RESEARCH LABORATORIES

Contributions to this report came from the following organizations:

ARCO Chemical Company

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- College Park Metallurgy Research Center
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DIMENSION STONE

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

1968

DIMENSION STONE

By William R. Barton

* * * * * * * * * * * information circular 8391

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DIMENSION STONE

by

William R. Barton[1]

ABSTRACT

Dimension stones, with their almost infinite variety, have a broad range of properties and uses. Natural stone was beyond doubt the first mineral commodity used by man. Today dimension stone has widened to encompass building exteriors and interiors, decorative and ornamental modes, statuary, monuments, paving, curbing, flagging, roofing, and miscellaneous categories such as blackboards, surface plates, and honestones. For many purposes, it competes with greater or less success with alternate materials such as concrete, metal, brick, plastic, or glass.

The almost ubiquitous geographic distribution of stone resources is the basis for a dimension stone producer industry in almost every State and in almost every land. In the United States, alone, dimension stone sold or used by quarries is valued at 2 million to 3 million dollars annually. Mining, finishing, transportation, and use technology have been modernized, resulting in a broader spectrum of stone products and new adaptions in use. Increased efficiencies also have been reflected in costs and prices and, coupled with gains that should be realized from current research, auger well for continued vitality of the ancient and honorable dimension stone craft.

INTRODUCTION

Dimension stone, a basic building and ornamental material, competes with an ever-increasing variety of alternate materials. In some instances it is limited by intrinsic disadvantages which include the relatively high cost of mining, preparing, transporting, and installing dimension stone. In addition, many buildings are now designed with a shorter life expectancy than formerly, permitting successful use of less enduring materials. However, recently there has been renewed recognition of the unique aesthetic appeal which stone offers together with its superior endurance and resistance to alteration of original properties by external environmental agents. The producer industry has modernized by adopting improved mining and machining methods, developing markets for waste products, by providing stone in new forms that can be installed at lower

[1]Supervisory physical scientist, Mineral Resource Office, Bureau of Mines, Knoxville, Tenn.; formerly with the Division of Mineral Studies, Bureau of Mines, Washington, D.C.

cost, and by developing a wider assortment of finishes which take full advantage of the ornamental appeal inherent in stone.

This report details the current status of the commodity and changes which have occurred since Dr. Oliver Bowles wrote his treatise on the subject, "The Stone Industries," published in 1939 by McGraw-Hill Book Company, Inc. It also serves to draw together and update information previously available only in scattered form in Dr. Bowles' series of Bureau of Mines information circulars and bulletins published between 1916 and 1963.

The report was designed to bring into a single publication all the fundamental information on the commodity by summarizing information on production, trade, use, substitute and alternate materials, and resources. The pertinent properties and principal specifications for stone are described along with exploration, mining, finishing, and use technology. A brief history and geologic background are also included. The geographic distribution, size, and structure of the industry are discussed, along with future outlook, costs, prices, tariffs, and legislation affecting the industry. A general cutoff date for inclusion of information in this report was its availability on or before January 2, 1968.

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CHAPTER 1.--CLASSIFICATION AND DEFINITIONS

All dimension stones can be classified under the detailed technologic classifications used by the petrographer. First by origin, that is, igneous, sedimentary, or metamorphic and then in subclasses based on mineralogical and chemical composition and diagnostic physical characteristics. The technical petrological system of classification, however, is too detailed and divorced from commercial custom for use by the dimension stone industry except during their own technological studies of various stones and stone deposits. For general use the industry has adopted a standard classification based upon the properties and uses of the stone. The categories are broader than the strictly scientific ones but satisfy the commercial needs of the industry, are comprehended by all, and permit almost all building stones to be readily cataloged.

There are eight principal classes of stone used for dimension purposes:

1. Granite (includes all rocks of granitoid texture, including those classified petrographically as granite, syenite, diorite, gneiss, gabbro ("black granite"), etc.

2. Limestone (includes also all dolomitic limestone and dolostone).

3. Marble (includes both calcareous and dolomitic marbles, onyx, travertine, serpentine, verde antique, etc. In essence those crystalline carbonate rocks and serpentines capable of taking a polish).

4. Sandstone (includes bluestone, brownstone, freestone, conglomerate, and arkose).

5. Quartzite.

6. Slate.

7. Greenstone (greenish stones not fitting other categories, usually colored by chlorite, epidote, or actinolite).

8. Basalt and traprock (includes diabase, dolerite, and similar fine-grained black rocks).

Occasionally one encounters a stone used for dimension purposes, such as schist, scoria, and soapstone, that cannot be properly fitted in the above classes so there is a ninth, little-used class--miscellaneous stones. There are numerous subclasses of stones in the classes listed based upon chemical or physical dissimilarities. One such example would be argillite, a subvariety within the slate category.

Having given this classification as background, definitions can be presented for some of the more common terms for stone and rock types as they are generally understood (1, 10, 34).[2]

Commercially, stone is the term for any natural rock material quarried or mined for constructional or industrial use in its natural chemical state and its physical character altered only by shaping or sizing. To an earth scientist, however, stone is any small, loose fragment or piece of rock.

Rock is stone still in place either as a formational component of the earth's crust or a part of a large mass or ledge that cannot be moved without subdivision. To a geologist, rock is any mass of naturally formed coherent mineral matter.

Construction stone is any stone used directly for construction purposes without chemical processing or calcining. It includes crushed stone, broken

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[2]Underlined numbers in parentheses refer to items in the bibliography at the end of this report.

stone, shaped (dimensioned) stone, and rough stone. It is divided generally into two categories--dimension stone (the subject of this report) and crushed or broken stone (to be discussed in a subsequent report of this series). Some quarries produce both types of stone but markets for crushed or broken stone are far more localized and market values are much lower than for dimension stone.

Dimension stone is a natural rock material that has been quarried to obtain blocks, slabs, or pieces which individually are required to meet size and/or shape specifications. It includes many types (defined later in the section on Use) such as rough stone, rubble, ashlar, slabs, blocks, or panels. It may eventually be sold with varying degree of or type of finish: Polished, cut, sawed, ground, or natural. It is selected by its combination of qualities which ensure satisfactory performance in a predetermined end use. The most prominent of these qualities are: Strength, durability, hardness, and ornamental value.

Commercially, granite (class 1) includes all feldspathic crystalline rocks of predominantly interlocking texture and with individual mineral grains visible to the naked eye. It includes gneiss, syenite, monzonite, granodiorite, anorthosite, and petrographic species intermediate between them. White, gray, pink, and red are the common colors, but greens, browns, and other shades are produced in some localities. Similarly textured feldspathic crystalline rocks dark gray to black in color are called black granite. These include the diorites, gabbros, and similar species of the geologist. An earth scientist identifies and names a particular granitoid rock generally by locality and prominent dark minerals present in the rock, for example Quincy aegerine-riebeckite granite. Commercially color is more important and names may be a simple statement of locality and color, such as Quincy gray, or imagination and salesmanship may triumph with terms such as "Royal Flamingo Pink."

Limestones (class 2) are sedimentary rocks composed essentially of calcium carbonate (calcite) or combinations of calcium and magnesium carbonates (dolomite). Calcitic limestone contains no more than 5 percent $MgCO_3$. Magnesian or dolomitic limestone contains 5 to 40 percent $MgCO_3$. Dolostone is a limestone containing more than 40 percent $MgCO_3$. Coquina is a special limestone variety consisting of fossil shells loosely cemented by calcareous cement. Travertine, scientifically defined as a limestone variety, is defined under marble because its appearance and ability to polish result in use more similar to marble than other limestones. In oolitic limestone, oolites, small spherical grains of $CaCO_3$ that resemble fish roe, are prominent.

Marble (class 3), in the strict sense, is recrystallized (metamorphosed) limestone with interlocking or mosaic texture composed of crystalline grains of calcite, dolomite, or both. In commercial usage, it is any calcareous crystalline rock or serpentine capable of taking a polish. On the same compositional basis as its unmetamorphosed equivalent (limestone), marble may be calcite marble, dolomitic marble, or dolomite marble. Onyx marble is a dense crystalline calcium carbonate precipitated from cold-water solutions rather than resulting from metamorphism of preexisting limestones. It is translucent with characteristic banding due to its mode of accumulation. It is sometimes

called Mexican onyx (true onyx, not onyx marble, is a hard-banded variety of chalcedony used for artistic and gem purposes) or, if it formed as stalactites or stalagmites in caverns, it is called cave onyx. Travertine, mentioned earlier under limestone, is related in origin to onyx marble but is regarded as having been precipitated from warm or hot ground and surface waters. It is a banded cellular stone, with numerous irregular cavities up to one-half inch in width arranged along the bands. The cavities are lined by microstalactites. These intrinsic features result in unusual textures and attractive patterns. Those that will take even a dull gloss polish are classed and sold as marble. Verde antique or serpentine marble is comprised of green to almost black serpentine (hydrous magnesium silicate mineral) crisscrossed by veinlets of lighter minerals, chiefly calcite or dolomite. They are not comparable with true marbles in either origin or composition but because of their ability to take a high polish and their marblelike veining they are so classified. The classic dark-green and white-veined countertop of an earlier-day American soda fountain was verde antique.

Sandstone (class 4), in commercial usage, is a sedimentary rock consisting mostly of grains of quartz, quartz and feldspar, or rock fragments of clastic texture bonded by various interstitial cements including silica, clay, calcite, or iron oxide. In its strict textural sense, the clastic grains would have to be in the sand-size range (one-sixteenth to 2 mm in diameter) but in commercial nomenclature the term has been broadened to encompass coarser-grained rock including conglomerate and other rocks so fine-grained that a geologist might call them siltstones. There are numerous compositional subvarieties of sandstone such as arkose (abundant feldspar grains), graywacke (abundant rock fragments), ferruginuous sandstone, micaceous sandstone, etc., that except for the terms arkose and graywacke have self-evident meanings. As just noted, conglomerate is an extremely coarse sandstone comprised of cemented gravel, pebbles, or boulders. If the component grains are angular it may be termed a breccia although to a geologist or mining engineer the term breccia also means crushed, broken, and granulated rock formed along a fault plane or zone. Puddingstone is a colloquial term for certain conglomerates. Bluestone is a dense, hard, fine-grained feldspathic sandstone which splits easily along the plane into thin, smooth slabs. It is commonly dark or slate gray in color but the term no longer has color significance. Brownstone is a feldspathic sandstone of brown to reddish-brown color caused by abundant interstitial iron oxide. Strictly used in its original sense, it refers to those Triassic sandstones popular for building in the Northeastern United States during the 19th century. Freestone is a sandstone that slabs with equal ease in any direction rather than along one plane only. It dresses without difficulty. Flagstone may be either a sandstone or slate that splits into large, thin slabs and is discussed further in the Uses section of this report.

Quartzite (class 5) is a metamorphic equivalent of sandstone that has become thoroughly indurated through firm cementation by secondary silica or by recrystallization so that it is essentially homogenous and fractures through rather than around the original sand grains. Its porosity is low and its fracture vitreous compared with the high porosity and dull, rough fracture of sandstone.

Slate (class 6) is a microgranular rock derived from metamorphism of argillaceous sedimentary rocks (shale, siltstone, or claystone). It is characterized by excellent and prominent parallel cleavage which is oriented independently from the original sedimentary bedding. The essential mineral constituents are quartz, mica, sericite, or chlorite with assorted minor accessories. The sedimentary rock, shale, with which slate is sometimes confused, is composed essentially of the original clay minerals and cleavage is primary, parallel with the bedding.

Greenstones (class 7) are crystalline metamorphic rocks of greenish color because of the presence of dominant greenish minerals such as chlorite, epidote, or actinolite. They are often the result of metamorphism of basic igneous rocks such as basalt lava flows, and they exhibit an interlocking texture.

Traprock or basalt (class 8) is a general commercial term for all basic igneous rocks too fine in grain to be called "black granite." The term is derived from "trappa" meaning a stairway, because basalt lava fields sometime exhibit a remarkable terraced or steplike appearance with successive flat, massive sheets rising in a series of benches like giant stair treads. In addition to extrusive flow rocks such as basalt, andesite, or dacite, the class "traprock" embraces igneous rocks that were intrusive (crystallized without reaching the surface) such as diabase and finer grained diorites, gabbros, pyroxenites, amphibolites, and peridotites. In some of the latter cases different producers may market the same type of rock as dimension traprock, greenstone, or if it is coarse enough to show megascopic graining and somewhat decorative, as black granite.

A few rocks are quarried for dimension stone that do not really fit in any of the above classes. Soapstone, talc, or steatite are names applied to a soapy-feeling dark gray or greenish rock containing 10 to 90 percent of the mineral talc and varying percentages of chlorite, amphibole, pyroxene, mica, calcite, or other minerals. Production of dimension soapstone has been small, mostly for special chemical-resistant use in laboratories and industrial plants. Other miscellaneous dimension stones include schist, mylonites, tuff, and other porous or scoriaceous volcanic rocks (sometimes called lava rock), diatomite, tripoli, and pumice. Assorted boulders and fieldstones also are used for rustic-style fireplaces, chimneys, and buildings such as resorts, hunting and fishing clubs, walls, and occasional residences. Even very unlikely building stone such as waste pegmatite and petrified wood has found application in some of the latter instances.

In addition to classifying and defining dimension stone by type, it may also be classified and defined by the use to which it is put and the form it is used in. An example of such a classification follows, but many of the terms are defined or understood differently in various countries, or even different parts of the United States, or by some industry segments:

Building structural, or architectural stone:

- Rough construction or architectural
- Dressed construction or architectural
- Ashlar
- Rubble
- Veneer

Ornamental stone

Monumental stone (including statuary)

Paving blocks

Flagging (including flagstone slate)

Roofing slate

Millstock slate:

- Structural
- Electrical
- Blackboard

The term "building stone" (also structural or architectural) embraces a wide variety of stones having a wide variety of finishes used in "structures" (buildings, bridges, walls, etc.). Rough construction or building stone consists of rock-faced blocks of various size and shape with the rough, as-quarried finish. A seawall may commonly be faced with such rough block. Cut, sawed, or finished stone consists of blocks and slabs shaped and sized accurately for a specified use or job. The surface has been finished by one of various tooling methods. Ashlar consists of blocks, generally small, with sawed, planed, or rock-faced surfaces. It may be laid in courses like brick work. The way in which it is trimmed, finished, or laid gives rise to many descriptive terms such as even, uneven, random, split-face, webwall, broken, etc., which are discussed in the section of this report on Uses. Rubble consists of rough irregularly shaped pieces of stone. It generally has one fairly good face and may be left entirely as broken out from the quarry or may be partly trimmed (rough-squared). Veneer are thin slabs which are used in nonload-bearing situations or as facing over other materials (such as concrete) to give the external appearance of thicker blocks or regular ashlar. A stone may be called ornamental if it has distinctive markings or color which make it prized for its decorative effect. It is often used with a highly polished finish but may not necessarily be suitable for monumental or statuary use depending upon carving characteristics. Monumental stone must meet exacting requirements such as uniform texture and color (or specified variations thereof), freedom from flaws, and general suitability for polishing and carving. Certain natural impurities in a stone which may cause subsequent staining in use can also disqualify a stone for monumental purposes. Some monumental stone is used in buildings and some building stone is used in monuments; however, not all stones are suitable for both purposes. In some cases

a quarry may use its perfect stone for monuments and market the rest (up to 85 percent of the stone quarried) as building stone. Some larger monuments such as the Lincoln Memorial or various mausoleums are actually buildings made of monumental stone. Statuary stone is a special variety of monumental stone that will not chip under carving. It must be easily worked, of dense, fine, uniform texture, and without foliation, bedding, or other planes of weakness. Paving blocks (including cobbles) are small, rectangular blocks originally used for areas under heavy traffic such as city streets. With the decline of the dray, they have practically disappeared except for minor purposes such as patios, borders for walks, driveways, and flower gardens, etc. Granite is the most commonly used stone for this purpose but it must be easily cobbable. Curbing consists of relatively thin slabs (mostly sandstone, granite, or quartzite) used along streets or highways to maintain the integrity of sidewalks and borders. These slabs must be resistant to impact and abrasion from wandering automobile traffic and are made of stone easily cleavable to fairly smooth faces. Flagging or flagstone consists of thin slabs (up to 3 inches in thickness) of siltstone, slate, fine-grained, thin-bedded sandstone, and occasionally limestone. These stones should be easy to split or be cleavable into slabs along natural, parallel, identifiable planes of weakness (bedding, cleavage, etc.). Rarely are sawn slabs used for flagging. Bluestone is a dense, dark-colored, easily split variety of sandstone used for flagging. Slate used for flagging is frequently that discarded as unsuitable for roofing or mill stock. Roofing slate must be smooth, easily cleavable (fissile), straight splitting, with no imperfections. It is generally one-eighth to one-fourth of an inch in thickness and 7 by 9 inches to 16 by 24 inches in surficial area. Millstock slate consists of blocks and slabs suitable for structural units, facing panels, electrical purposes, blackboards, etc. It must be even-grained and preferably not highly fissile. In addition, electrical slate requires low conductivity and must be drillable without chipping. For blackboards, slate must be of suitable, even color, able to take a very smooth finish, and low in reflectivity.

CHAPTER 2.--PROPERTIES AND SPECIFICATIONS

Dimension stones are of almost infinite variety. Consequently, they have a broad range of individual chemical and physical properties. Wise use requires that the properties of an available stone be such that they can match or exceed specifications established for stone in particular end-use situations or environments. The chemical and physical properties of rock vary principally because of differences in texture, manner of formation, and mineralogical (and hence chemical) composition. In order to determine whether the properties of a given stone are suitable for certain purposes, it is customary to subject the stone to various tests such as strength, absorption, specific gravity, wear, toughness, etc., and so determine if it can meet specifications

Since stone is used as a physical substance, chemical properties are of lesser importance than physical except that the chemical composition does determine many physical properties of the stone, in particular response to weathering. A petrographic examination will permit a close approximation of the ultimate chemical analysis. A chemical analysis of the stone has relatively limited usefulness to determine the behavior of the stone when in use

in a given environment. However, if possible deleterious minerals are detected by the petrographic examination (such as those which might oxidize), then a chemical analysis would be advisable. For exterior use, the mineralogical components of the stone should be resistant to natural and special environmental chemical weathering. In particular, calcitic stones or stones with calcite cement are susceptible to acidic smoke, fumes, acidic rain water, and some ground or soil water. In chemically severe atmospheres, such as in large Eastern United States industrial cities, even granite may suffer some superficial attack. Oxidizable minerals, particularly iron-bearing ones such as pyrite, if present may cause unsightly staining, discoloration, or corrosion of the stone if used inappropriately. Chemical and mineralogical compositions of typical dimension stones are given in tables 1, 2, 3, and 4.

TABLE 1. - Typical percentage chemical analyses of some igneous natural building stones

Stone	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O
Granite....................	68.3	14.8	1.3	2.7	0.8	2.3	2.7	5.0	1.1
Syenite....................	64.7	10.5	1.1	7.4	5.2	3.1	2.2	3.6	.9
Granodiorite...............	59.9	16.4	3.0	3.7	3.1	6.3	4.1	2.5	1.1
Diorite....................	52.1	16.4	3.7	6.0	4.1	7.3	3.7	2.3	1.1
Gabbro.....................	44.9	15.4	2.3	12.4	10.9	7.5	3.0	.5	.8
Granite porphyry...........	73.5	13.7	1.2	.7	.4	1.2	4.4	4.5	.4
Diabase....................	48.9	20.9	2.0	9.4	4.4	8.0	3.1	1.8	1.2
Basalt.....................	51.7	17.9	7.2	1.0	2.8	6.9	4.2	1.6	1.2

TABLE 2. - Typical percentage chemical analyses of some sedimentary natural building stones

Stone	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	CO_2	H_2O
Sandstone.........	93.0	3.0	-	1.0	0.5	0.8	-	-	-	1.1
Arkose............	76.1	8.7	-	3.5	4.3	1.3	1.1	0.5	-	1.7
Limestone.........	3.8	1.0	0.4	-	1.2	51.3	-	-	41.6	-
Dolomite..........	.1	.1	-	.3	21.2	30.6	-	-	46.9	.2

TABLE 3. - Typical percentage chemical analyses of some metamorphic natural building stones

Stone	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O
Quartzite...............	96.1	2.2	0.1	-	0.6	0.5	-	-	0.6
Gneiss..................	70.2	13.9	1.1	3.1	1.3	3.1	3.3	2.7	.7
Slate...................	61.6	16.3	4.1	2.7	2.9	.5	1.3	5.5	3.4
Marble[1]...............	-	.1	Trace	-	.4	55.8	-	-	-
Dolomitic marble[2].......	-	-	.2	-	20.7	30.7	-	-	-
Serpentine..............	40.0	3.4	-	5.3	39.2	-	-	-	12.1

[1] CO_2 = 43.8 percent.
[2] CO_2 = 46.7 percent.

TABLE 4. - Average percentage mineralogical composition of natural building stones

Stone	Quartz	Ortho-clase	Plagio-clase	Augite	Horn-blende	Biotite	Musco-vite	Epidote	Rock glass
Granite.....	30	41	8	-	-	3	3	1	-
Diorite.....	8	7	30	3	27	4	.1	5	-
Gabbro......	.5	-	44	28	9	2	-	1	-
Diabase.....	-	-	44	46	-	-	-	-	2
Basalt......	-	-	36	35	-	-	-	-	21
Sandstone...	79	5	.3	-	-	.2	1	-	-
Quartzite...	84	3	-	-	1	2	2	2	-
Limestone[1]..	6	-	-	-	-	-	-	-	-
Dolomite[2]...	5	-	-	-	-	-	-	-	-
Marble[3].....	3	.2	.2	-	-	-	-	-	-
Slate.......	29	4	-	-	-	-	55	2	-

[1]Calcite = 83 percent; dolomite = 8 percent.
[2]Dolomite = 82 percent; calcite = 11 percent.
[3]Calcite = 96 percent.

The desirable physical properties for a dimension stone vary with the intended end use. Strength, durability, and appearance are perhaps the most important physical qualities of a dimension stone, but many others also affect its utility and value. The physical properties of a stone may be defined in terms of physical constants which can be measured by various test procedures (see table 5).

TABLE 5. - Average physical properties of selected natural building stones

Stone	Compressive strength, psi	Absorption, percent	Toughness, index	Abrasion by Los Angeles test[1]
Granite.......................	25,000	0.30	9	41.5
Diabase, gabbro, "black granite," etc................	41,800	.21	20	15.3
Sandstone.....................	22,900	1.66	12	58.7
Quartzite.....................	31,000	.24	19	26.1
Limestone.....................	11,500	.61	8	33.8
Dolomite......................	20,200	1.09	8	27.1
Marble........................	13,600	.21	5	54.2
Dolomite marble...............	28,900	.25	6	42.1
Slate.........................	21,800	.36	18	-
Serpentine....................	43,000	.74	13	18.5

[1]See ASTM for standard method.

Crushing strength indicates the ability of stone to sustain a load (weight) without failure. Building stones with a crushing strength of less than 3,000 psi (pounds per square inch) are rare and even that value is much higher than loads imposed during any conventional use. For example, at the base of the Washington monument, the load bearing on the stone is only 600 psi. With the introduction of nonload-bearing curtain wall construction, crushing

strength for such use is much less important. Kessler (61) quoted the following typical value ranges for various construction materials in psi as follows:

Granite	13,000 to 47,000
Marble	8,000 to 27,000
Limestone	2,600 to 28,000
Sandstone	5,000 to 20,000
Quartzite	16,000 to 45,000
Serpentine	11,000 to 28,000
Cast stone	1,600 to 21,800
Brick	1,000 to 20,000

Although the test may assure the buyer of strength he may not really need, many feel that this physical property may also relate to ultimate durability over many years of use.

Transverse strength (flexural strength) is a valuable physical constant to determine because stones are often placed in positions of unequal pressure or where they may be subjected to bending stress such as in sills, lintels, window caps, and so forth. The significant property measured is actually the modulus of rupture in psi. The equation is three times the weight bearing on the middle of the span (W), times the length of the span (L), divided by twice the breadth of the span (b), times the thickness of the span (t) squared, or: $R = \frac{3WL}{2bt^2}$. Typical ranges for various stones, quoted in National Bureau of Standards publications, in psi are as follows:

Granite	1,380 to 5,550
Marble	600 to 4,000
Limestone	500 to 2,000
Slate	6,000 to 15,000
Serpentine	1,300 to 11,000
Sandstone	700 to 2,300

Under uneven loads stones may fail due to differential pressure. In general the compact stones have higher transverse strength than those with loosely packed mineral grains.

Hardness of stone is a composite function of the individual mineral constituents and is dependent upon their relative hardness and abundance (percent of composition), texture, fabric, and porosity. To date, there is no standard way to measure rock hardness although many methods have been suggested and some are being studied. This property is rarely reported for dimension stone.

Toughness or tenacity is the measure of resistance to impact. It is important for stone used in floors, curbing, steps, or wherever it may be subjected to sharp blows that may cause spalling. The property is measured in foot-pounds of energy absorbed by a rock before failure.

Abrasive, or wear, resistance also is an important property for stone floors, pavements, stairs, and so forth. Both composition and texture interrelate with this property. A tight texture will resist abrasion best.

Polymineralic stones may undergo differential wear and some grains may cleave and fall out even though they are individually resistant. The index of abrasive hardness (Ha) is a function of the original specimen weight, the bulk density, and the loss of weight during testing. Typical Ha index ranges for various types of stone are as follows:

Granite.............	37 to 88
Marble...............	8 to 42
Limestone...........	1 to 24
Sandstone...........	2 to 26
Slate................	6 to 12
Serpentine..........	13 to 110
Travertine..........	1 to 16

Fabric--or as it is generally called texture--is the grain and cement pattern relating to sizes, shapes, and the arrangement and mutual relations of component grains and crystals. These factors more than any other determine the intrinsic properties of the stone and its response to various tests and environments. Interlocking grains, strong cement, or dense grain packing generally indicate a strong durable stone. Weak cement, or looser packed grains, or some granular fabrics may be indicative of less resistant varieties. Many descriptive terms are used to describe texture since it is a qualitative rather than a quantitative characteristic. A rock may be equigranular, that is all component grains may be approximately the same size or it may be inequigranular, with grains of markedly unequal size, or again it may be porphyritic with relatively large, prominent grains of one or more mineral components in a matrix of markedly finer texture. The grains may be euhedral, angular, subhedral, subround, anhedral, or rounded. These are terms referring to form of contained crystals or grains. Textural relations between grains may be described as interlocking (by mutual grain penetration), mosaic or granulitic (noninterlocking with mutual boundaries), or clastic (naturally cemented fragmental grains without interlocking or mosaic relationships). Textural terms and descriptions can become highly technical and involved and for further discussion the reader should consult a good petrography text (51, 55, 84). Even definitions of grain size will vary according to the text used, the size classification used, or the type of stone discussed. For building stone a typical scale might be: Grains averaging more than 2 inches, very coarse; more than 0.5 inch, coarse; more than 0.2 inch, medium; more than 0.1 inch, fine; more than 0.01 inch, very fine; less than 0.01 inch, aphanitic (crystalline), or silt (sedimentary).

Porosity and absorption have a direct influence on strength and weathering and, through these factors, on durability. Porosity is the volume of pore space in a stone and absorption is the amount of liquid a stone will absorb on immersion. The two properties are related to each other in a variable way. If all other things were equal, porosity and absorption would be in direct proportion to one another but pore size, shape, and interconnection have the primary influence on absorption, rather than simply the proportion of pore space. Where pore spaces are of subcapillary size, absorption is low. If pores are capillary size or larger, absorption is increased with concomitant susceptibility to frost action and chemical weathering. Extremely large pores

however, reverse the effect by promoting drainage and surface evaporation and thus minimizing the effects of frost action.

High porosity may or may not indicate high absorption but high absorption will indicate high porosity. Absorption, therefore, is the more important property rather than absolute porosity. Porosity will affect strength but strength can be more precisely determined by direct physical tests. In general, stones with compact and interlocking textures will have low porosity. This is indicated by the following range of values (in percent of pore space by volume) for various stone types (61):

Granite	[1]0.4 to 3.84
Marble	.4 to 2.1
Slate	.1 to 1.7
Quartzite	1.5 to 2.9
Sandstone	1.9 to 27.3
Limestone	[2]1.1 to 31.0

[1]Rarely above 0.6.
[2]High value probably for coquina.

Absorbed water will affect the strength of a stone. Dry stone, with exceptions, usually has a crushing strength several thousand pounds per square inch stronger than the same stone when it is wet.

Stone colors can be rigorously described in terms of the Rock-Color Chart of the Geological Society of America or the National Bureau of Standards Centroid Color Charts and Dictionary of Color Names (National Bureau of Standards Circular 553 and Supplement). Commercially, however, many promotional terms are coined to tempt the buyers imagination such as pearl-beige, mahogany, ebony, coppertone, royal red, and so forth. To determine actual color tone in quantitative terms, samples of such stone must be viewed. The stone should be viewed in the finish with which it will be used and at a distance. This gives the so-called architectural color which may differ considerably from the original rock color. Color in rock is basically determined by the colors of the constituents of the monomineralic or polymineralic rock. The shade of color will vary broadly depending upon stone finish. Generally, polished stone will be darker than rock-face finish and tooled surfaces will be lighter. One method to classify stone color by color chart would be to spin a small plate of stone so that the colors of the constituent minerals blend together and to compare the effect with the color-chart standards.

Some stones will change color after a fresh surface is exposed to the atmosphere. This can be due to oxidation of contained iron minerals, to organic matter and bacteria, or to attack by acidic industrial atmospheres. Some postinstallation color changes may be desired by architects as a mellowing effect and are considered by the architect during stone selection.

Durability is the service life expectancy of the stone for which there is no generally accepted quantitative test or measure. The problem is that the natural weathering processes are so slow, complex, and subtle that laboratory measurements are difficult to translate into terms of what might be expected

in a natural environment. To reduce the time of a typical laboratory test cycle to reasonable bounds, the durability test must be so severe that its validity compared to natural atmospheric and frost action is always questioned. The final test that can remain unchallenged is the actual service of a stone in use over a span of years. The American Society for Testing and Materials, Committee C-18 on Natural Building Stones, is studying means of quantifying laboratory durability tests, but many problems must be solved, the most basic of which is obtaining truly representative test samples from rock which may have natural variations repeated at random over short distances.

Extrinsic factors also affect building stone durability. Stone highly satisfactory for use indoors may be very susceptible to weathering by rain (solution), frost, acid atmospheres, or abrasive action of windborne dust or sand. Proper installation may also be a factor. An example is certain sandstones which are perfectly durable if laid with bedding planes horizontal but which will spall and erode badly if laid with bedding planes vertical.

In summary, durability cannot be easily measured or defined; for it depends upon different qualities and factors according to mode or place of use. It is the length of time a stone will continue to serve in the form and fashion originally intended. For a grave monument this may be until loss of polish or pitting and spalling occur; in a structure it might mean until loss of minimum required strength. The behavior of a given stone both in nature and existing structures or monuments remains the empirical and best guide to durability.

The specific gravity, or ratio of weight to given volume of rock, is an important property for architects and builders to consider. Structures must be designed to support the weight of stone per unit area. Depending upon the mineralogical composition of the stone, the packing density of grains and crystals, and type and degree of cementation, the specific gravity of a given variety of stone may range widely. Specific gravity is measured in terms of weight per unit compared with water which is considered 1.0 with a weight 62.5 pounds per cubic foot at 62° F. Thus, a stone weighing 125 pounds per cubic foot has a specific gravity of two. Representative specific gravities and weights in pounds per cubic foot for various stones are given in table 6.

TABLE 6. - Specific gravity and unit weight of various dimension stones

Stone type	Specific gravity		Pounds per cubic foot	
	Average	Range	Average	Range
Sandstone	2.42	2.2 to 2.7	151	138 to 168
Quartzite	2.64	2.56 to 2.7	165	160 to 168
Limestone, dolomite	2.65	[1]1.87 to 2.80	166	[1]117 to 175
Granite, gneiss	2.70	2.6 to 2.75	169	162 to 172
Slate	2.70	2.6 to 2.8	169	162 to 175
Marble	2.72	2.6 to 2.86	170	162 to 179
Basalt, black granite, gabbro, greenstone, etc	2.96	2.9 to 3.2	185	181 to 200

[1]Low value for stone with 31 percent porosity.

Density that is weight of stone per cubic foot must also be determined in order to determine stone reserves by weight. In field study the volume of stone in a deposit can be measured by surveying and exploration techniques but if reserves in tons (not really necessary for dimension stone) are quoted, then density must be used to convert cubic feet or yards to pounds or tons.

The property of resistance to weathering, disintegration of dimension stone by weathering processes, is one not easily measured and means of measurement have not been resolved; as was pointed out previously in the discussion of durability. Perhaps the most severe weathering mechanism is physical: Frost or temperature-change action.

The primary temperature-change agent is the alternate freezing and thawing of water in pores, seams, and fissures but to a lesser extent it also is expressed in the alternate contraction and expansion of the mineral grains themselves during temperature cycles. A humid climate combined with frequent diurnal changes across the freezing temperature of water will of course result in the greatest exfoliation due to frost. Even a hot, arid climate, however, will cause spalling due to loosening of mineral grains by alternate expansion and contraction.

In addition to physical weathering, chemical actions are the other major causes of weathering and can be classified as being either due to constitutional factors or environmental factors. Constitutional factors include capillarity of pore spaces, mineral composition, and texture. As mentioned earlier iron sulfide minerals may oxidize and not only stain the stone but give rise to sulfuric acid solutions which attack other constituent minerals and, by altering them, cause further mechanical disruption in the stone. Other iron minerals such as magnetite, siderite, and ferruginous amphiboles will weather more slowly but result in eventual pitting of the surface. A texture with interlocking grains will, of course, best resist pitting due to grain spalling.

Soil and atmospheric waters and industrial fumes are the important environmental factors. If a stone with capillary-size pores is used in a base course, it will actually draw water upward, into itself, from the soil. Water containing carbon dioxide will slowly alter feldspar into clay. Acid waters and fumes will slowly leach carbonate minerals with resultant slow crumbling of the stone.

Weathering properties, like durability in general, are difficult to quantify for the same reasons. Laboratory tests are so environmentally different from actual use over many years that to try to relate one to the other and to validate test results staggers the scientific mind.

Numerous specifications and tests have been set forth to determine whether a stone meets standards. For a stone used in Federal building projects, specifications are set forth by the Public Building Service of the General Services Administration, other standards have been adopted and published by the American Institute of Architects. Perhaps the most widely accepted specifications, and on which many other specifications and tests are

based, are those of the American Society for Testing and Materials, Committee C-18, Natural Building Stones. The committee reflects a broad range of interests: Producers, consumers, and the general public. Its members include architects, engineers, corporation executives, Government specialists, scientists, and consultants. Careful research is required before any test or specification is voted on. If accepted by the committee, the proposed specification or test is published with a tentative status for at least 2 entire years before it is raised to a standard. This allows sufficient time for all valid questions or objections to be heard. The Society's designation consists of a series of symbols. The first such as C170 is the fixed identification, the second such as 65 indicates the year of adoption, followed by a "T" if tentative. All standards are periodically reviewed and revised if necessary.

Standards are designed to protect both the consumer and the producer of stone and to recognize the appropriateness of various stones for various uses. With manmade materials, properties can be controlled in the manufacturing plant and conditions of laboratory testing can easily be established and controlled. For natural building stone, however, quality can only be controlled by selection. Tests can be applied in the laboratory to small samples but not to the stone in the quarry as a whole. Because natural stone is variable, it is always problematical to obtain a representative test sample. And once a presumed representative sample is obtained, the specimen must be prepared very carefully with standard techniques, orientations, sizes, and shapes because, unlike artificial construction materials like concrete, stone samples cannot be molded or cast from a uniform batch. Whatever specifications are framed, these complications must be recognized by setting less strict limitations for stone than for manufactured materials. As noted earlier, the greatest problem is to appraise the probability of endurance of a stone. To date, no single test for durability has been generally accepted, but a series of tests on various stone properties, keyed to proposed mode of use and expected climatic environment may provide valuable guidance. The most recent (1964) book of ASTM standards lists the following currently accepted specifications and tests for natural building stones:

C97-47	Absorption and bulk specific gravity.
C99-52	Modulus of rupture.
C119-50	Definitions of terms relating to natural building stones.
C120-52	Flexture testing of slate, modulus of rupture, and modulus of elasticity.
C121-48	Water absorption of slate.
C131-55	Abrasion resistance by Los Angeles test.
C170-50	Compressive strength of natural building stone.
C217-58	Weather (acid) resistance of natural slate.

C241-51	Abrasion resistance of stone subjected to foot traffic.
C406-58	Roofing slate.
C503-62 (R64)	Exterior marble.
C543-64T	Slate blackboards.
C (Proposed)	Dimension limestone.
C (Proposed)	Dimension sandstone.

(In addition general ASTM tests of interest include: Young's modulus of elasticity E-111-61; shear modulus, E-341-61; and Poisson's ratio E-132-61.)

An existing standard on dimension granite (C422-58T) has been withdrawn as well as a test method (C218-48T) to determine the combined effects of temperature cycles and weak salt solutions in natural building stones. Revised test procedures and specifications for both standards are under study by Committee C-18.

Published standards may cover all or one of the following: Specification scope, definitions, material applicable to, general characteristics and requirements of the material, categories, physical or chemical requirements, dimensions, workmanship and finish, sampling procedure, methods of test, inspection of product, certification, and marking. Individual standards, the entire ASTM book of standards, or portions of it may be purchased from: American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103.

Specifications for stone to be used in Federal building projects may be obtained by addressing a request to Public Building Service, General Services Administration, Washington, D.C. 20240.

CHAPTER 3.--HISTORY

Natural "dimension" stone was beyond doubt the first mineral commodity used by man. It probably was first used when Eoanthropus or Sinanthropus built stone enclosures for his fire and low stone walls across the mouth of his cave to keep out weather, predatory animals, and unfriendly neighboring clans. It was only one step further, requiring no great ingenuity, to start throwing pieces of the wall at attacking enemies, man or beast, taking man's weaponry beyond the wooden club stage and advancing him into the stone age of lithic tools, weapons, and artifacts. As time progressed he learned to shape (or dimension) rocks to improve their utility for a specific purpose and how to fit blocks of stone together to permit him to build a secure rock "cave" where he wanted shelter--near water and game--not just where nature had provided them.

As early as 12,000 years ago our ancestors learned to quarry and shape blocks as loose material close at hand became exhausted, and to bank and shape

blocks together with crude clay, lime, or gypsum mortars. They soon realized that some types of stone could be more easily quarried, afforded larger and sounder blocks, or were more beautiful, stronger, or more enduring than others. From the most remote periods of civilization, stone has been used to perpetuate the memory of individuals, to immortalize their noble achievements, or to glorify their deities. Ancient memorials ranged from simple cairns and monoliths to complex structures. Long before the Christian era, man learned to transport huge dimensioned stones weighing up to 90 tons, culminating in the grand pyramids of Egypt. Later the Greeks, Romans, and Moguls added artistry to engineering and the science of architecture was complete, resulting in edifices such as the Parthenon, the Taj Mahal, and the Coliseum. Later, exquisite cathedrals were the architectural wonders of medieval Europe. Until the modern advent of concrete, most paved roads and sidewalks were of stone block or slab.

From time to time tastes in stone have changed. A typical example is the popular brownstone of the 19th century whereas today limestone, marble, lighter sandstone and granite are popular. For modern use, beauty, taste, and imagination have skillfully been blended with stones natural strength and endurance in a broad range of applications. No longer, however, are massive blocks of stone commonly used except in rare monuments or prestige buildings. Most stone buildings are really concrete and steel sheathed in thin stone veneer. But where beauty and durability are desired, stone exteriors or stones combined with glass, metal, or other materials remain the choice. Even in modest homes and structures, stone veneer, trim, ashlar, or slate roofs are tastefully applied. For interiors, steps, walls, floors, fireplaces, and many other locations stone remains the premier material. Decoratively, its myriad uses include thin, translucent panels of marble or onyx in place of windows, table tops, bathrooms, flagging in patios, etc. In traditional burial grounds memorial stones and mausoleums are stone. Slate blackboards are still the most durable surface for instructional use in our schools. Paving use of stone has almost disappeared but stone curbing is still common because it is more resistant to impact of vehicle wheels than competing materials and also because it has superior ability to withstand road salts used for snow removal. Only a very few natural grinding stones or wheels are still made in competition with the superior artificial abrasives.

CHAPTER 4.--USE

A review of the use to which dimension stones are put is best undertaken by following a modification of the use classification given earlier in this report; that is, exterior building, interior building, decorative and ornamental, monumental and statuary, paving, curbing, flagging, roofing slate, millstock slate, and miscellaneous uses such as surface plates and honestones.

In the building stone category, the industry has seen revolutionary changes in use technology. With increased popularity of lower cost steel and concrete construction, the widespread use of massive dimension stone blocks for load bearing structural use declined to almost nothing. However, the stone industry slowly adapted to these technological changes and emphasis is now placed on the economical production of thin veneer slabs or small blocks

for both interior and exterior application. Many available colors and varieties of textured surfaces are produced and increasingly attract architects who wish to avoid the necessarily limited aesthetic effects that concrete, steel, and glass can achieve (fig. 1). More and more the arbiters of taste in building are turning to the broad spectra of hues and the many sensually gratifying textures that can lend diversity to our urban scene by using natural dimension stone, often as veneers over concrete or in nonload-bearing spandrels. Decorative, ornamental, monumental, and statuary use of stone also set back by innovations such as the bronze-plaque-only memorial park and austure glass and shiny-metal architecture are again vigorously expanding as consumers try to find means of personal expression in our increasingly sterilized, cradle-to-grave, punch-card society. Similarly, stone flagging, curbing, and paving and slate roofs appeal to those who want the genuine, lasting qualities of stone instead of less durable and less beautiful manmade or machine-made substitutes.

FIGURE 1. - Masonic Temple. *(Courtesy, Vermont Marble Co.)*

Exterior Building

As just noted, massive blocks of building stone are rarely used these days. Their most common use is as rubble and rough blocks for seawalls, jetties, retaining walls, and to face earth levees and dams. Such blocks may be roughly squared for better fit or may be laid up in their as-quarried shape. In addition, occasional monuments and mausoleums are still built, using massive stone construction that calls for finished blocks. In the present United States economy, however, such building is not common. Cornices and trim may upon occasion be of stone blocks in large concrete or brick buildings. Slabs and ashlar are the common architectural stone units in use today.

Stone in slab form is generally used as a veneer over other materials or as a thin, nonload-bearing curtain wall using spandrels hung from the structural members of the building. As a precast veneer backed with concrete, the stone generally ranges from seven-eighths of an inch to 4 inches in thickness depending upon the strength and cost of the stone and on how easily it cuts into slabs. Stone sliced any thinner would be difficult to anchor and bond to its backing and might crack under relatively small, unforeseen stress or use. The backing, generally 5 or 6 inches of white portland cement, lightweight aggregate concrete is usually reinforced with welded wire fabric or truss-steel studs. If the stone is not preset, it may be cemented to its backing, or setting bed, at the construction site. A cement putty (cream or butter) of pure portland cement and water is generally used for the bonding agent. These stone veneer slabs may be any size with all combinations of dimensions from brick and tile size up to as much as approximately 5 by 10 feet, occasionally even larger. Unusual effects can be obtained by using unusual-shaped pieces in the veneer, such as long, thin parallel strips. Longer slabs may be grooved so that they appear to represent several pieces of stone laid in courses. Such veneers are often referred to as modules or as modular pieces. As an alternative to backed veneers, the slabs may be set in metal frames to be hung as spandrels from the load-bearing frame of a structure. Usually such slabs are only 1 to 2 inches thick since weight must be held to a minimum in such use. A lightweight insulating material up to 2 inches in thickness generally backs the stone slab in such use. A special use for thin slabs of onyx and other marbles up to seven-eighth inch in thickness is as translucent panels that can be used to admit light in place of windows. The same materials used as veneer may appear opalescent.

Ashlar or ashlar veneer in a wide variety of stones, finishes, shapes, and settings is extremely popular in smaller public and commercial buildings and residences. Standard ashlar veneer thicknesses are 3, 3-1/2, and 4 inches and common heights are 2-1/4, 5, 7-3/4, and 10-1/2 inches. The ashlar may be laid in various ways. As even courses, each horizontal range of stone units extending the length of the wall is a single height with succeeding courses the same or different heights. In uneven courses various height ashlar pieces are combined to equal each other within ranges. For example, a 2-1/4-inch ashlar plus a 1/2-inch joint plus another 2-1/4-inch ashlar equal an adjoining 5-inch ashlar. Similarly, a 7-3/4-inch piece, a 1/2-inch joint, and a 2-1/4-inch piece equal the height of a 10-1/2-inch slab, and so forth. Mosaic ashlar consists of pieces which are laid up in irregular fashion without a

pattern to their arrangement. Frequently, the ashlar pieces are irregular in shape or broken, and webwall or random field stone ashlar are alternate terms for such patterns. The most popular ashlar mortar is a 2-1-6, that is, 2 parts nonstaining portland cement, 1 part hydrated lime, and 6 parts clean, sharp sand. Depending upon stone density and thickness, a ton of ashlar will generally provide 35 to 65 square feet of wall surface.

The original and virtually the only use for slate for many years was for roofing. Because of its durability, attractiveness, and nonflammability slate is a superior material for such use. The essentials of slate for roofing are straight, uniform, and smooth cleavage, an attractive color that does not fade or fades uniformly, and absence of mineral constituents that react with relative ease under the influence of atmospheric agencies.

In the United States, slates are sold by the "square"--enough slate to cover 100 square feet with a 3-inch head lap. In France and England, the unit is a "mille," 1,200 slates of any given size and 60 additional to cover loss by breakage. Slates range in size from 7 by 9 inches to 16 by 24 inches, and the number of slates required for a square ranges from 85 to 686 according to their size. Ordinary slates range from one-eighth to one-fourth inch in thickness; three-sixteenths of an inch is a well-established thickness. The weight of a square of average roofing slate is 650 pounds.

Most roofs are now constructed of alternate materials such as granule-coated asphalt shingle, so that slate for roofing is now infrequently encountered.

Interior Building

Architectural dimension stone used inside buildings has two primary intrinsic values: (1) Its decorative effect and (2) its resistance to failure under heavy or abrasive traffic. When used for example as floors or steps both properties combine to make stone the logical material for use.

Marble in thin slabs or veneer is a favorite stone for interior use. Both white and colored marbles are prized for their decorative effect and are widely used in wall panels, columns, counter fronts and tops, baseboards, trim, ceilings, and for other similar purposes. It is usually polished or given a gloss finish. Some of the highly decorative bastard marbles such breccia, verde antique, onyx marble, and travertine are favored because of their attractive coloring or distinctive texture. Marble slabs for flooring and thin blocks for stair treads are reasonably resistant to abrasion but for such purposes are left with a smooth but dull finish. Because marble lends its own special brand of luxury and distinction to a building, it is the particular choice of banks, affluent corporations, governmental buildings of some types, certain institutions, and other locations where the architect wishes to convey to his audience an aura of strength, affluence, permanence, or dignity. The variegated colors, textures, and patterns also provide the architect an opportunity to use them in infinite ways and combinations and thus give his interior design a personal uniqueness. Slabs may be matched in various ways to give continuous or broken patterns. Two of the most popular are (1) "book

matching" where two adjoining slabs are matched along one edge and (2) "diamond or quarter matching" where four slabs are matched with each other along two edges in a diamond or similar design (fig. 2). The latter pattern requires a constant vein or grain and usually much stone is wasted. Certain marbles and onyx marbles may be cut in very thin slabs so they are translucent to light to attain striking interior effects. In cleaning marble, acid or other highly corrosive materials should never by used, and abrasive cleaners must be avoided on polished finishes. A soluble, mildly alkaline cleaner diluted in water should be used and this solution should be rinsed off thoroughly from the marble.

Limestone ashlar and ashlar veneer is also used indoors for decorative room dividers, fireplaces, walls in game rooms, and trim. Sandstone ashlar and veneers, especially the more ornamental types such as those with color banding are widely used for interior construction and decorating. Sandstone (including quartzite or bluestone) is also used for similar purposes and, in addition as flagging it is often used for floors. Various colors may be combined to make attractive floor patterns and borders. Because of its superior resistance to abrasion, sandstone is also popular in steps where heavy traffic is encountered. Its durability, combined with its nonslip surface, recommends it particularly for institutional use such as in hospitals and schools. Granite (including "black granite") ashlar and ashlar veneer are also used for decorative interior walls, and polished slabs are used for wall panels in commercial and institutional buildings. Finer grained igneous rock such as "basalt" are rarely used for interiors because of their sombre colors, except when a contrasting trim is desired for use with a lighter colored stone. Slate is used to some extent for interior flagging, tiles, steps, baseboards, sills, and occasionally for wall panels (fig. 3).

Monumental, Ornamental, and Decorative

Stones, more particularly those with distinctive color or texture, are often cut and polished or carved for monumental and other decorative use where appearance is the prime requisite. Actually, a sharp dividing line between buildings and monuments does not exist, because the more elaborate type of monument such as the Lincoln or Jefferson Memorials in Washington, D.C., or large mausoleums, are true buildings as far as construction goes. The prime difference is that the stone is chosen with special attention to beauty as well as for its structural qualities. Some, but not all, building stones are suitable for monuments, ornaments, statuary, or other decorative use. Conversely. a stone suitable for use in a cemetery as a grave marker does not require the structural properties needed when used in buildings and memorials; it must be free of mineral knots or schlieren, hairlines, impurities, incipient seams, or other defects and have uniformity of desired textural or color features. Many memorials are of polished stone, and particularly on granitic rocks, spots, streaks or other defects invisible on a natural rock face will be prominently displayed when polished. Because of this, stone to be polished must be selected with unusually great care and in some cases such as granite should be polished early in processing to avoid wasting labor on a flawed stone. If the stone is to be inscribed with lettering, the polished surface must also offer a color contrast to the tooled lettering. Stone

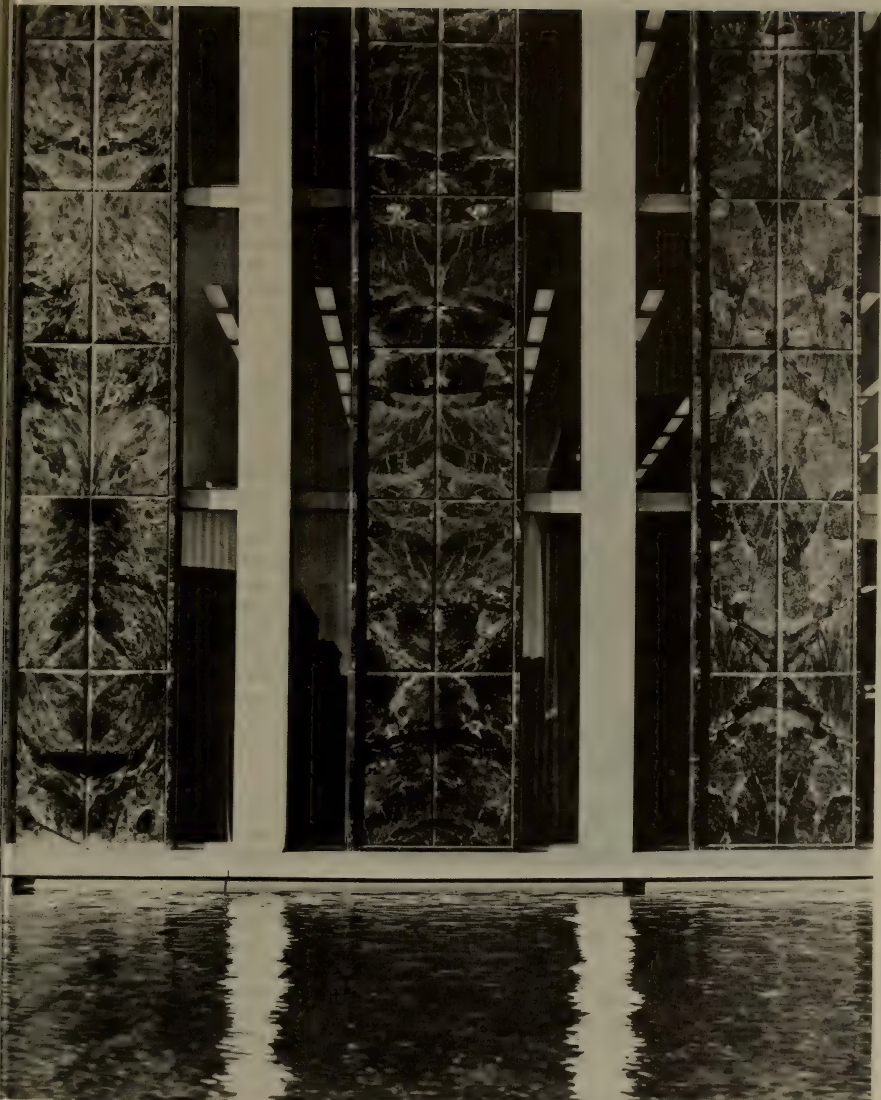

FIGURE 2. - Diamond-Matched Verde Antique. *(Courtesy, Vermont Marble Co.)*

FIGURE 3. - Bas-Relief Carved Slate Wall Panel.
(Courtesy, Pennsylvania Slate Producers Guild, Inc.)

containing certain impurities must be avoided for either polished or unpolished use. For instance, if crystals of iron sulfide minerals, pyrite, pyrrhotite, or marcasite are present, they may be oxidized by weathering and cause unsightly rust stains. Monuments and memorials with few exceptions consist of granites and related rocks or marbles.

Stone with ornamental properties are also widely used for decorative purposes such as counter and table tops, altars, lamps, ash trays, bookends, and gift-shop novelties. Granite, marble, verde antique, and onyx marble are most widely used for such purposes. Kitchen and bathroom use of marble in items such as counter tops, bathtubs, and shower stalls are of increasing vogue in recent years.

The most valuable decorative stone is that suitable for statuary or other carving, the preferred media being pure white, fine-grained uniform marble. In all cases, the characteristic of not splitting or chipping under the artist's chisel is the prime requirement, and because softer rock such as marble can be worked on faster, it is far more widely used for statuary than the harder, tougher rocks like granite.

Industrial and Other Special Uses

There are numerous uses other than building and ornamental that require dimensioned blocks of stone. Stone curbing, rather than concrete curbing, still finds application along highways and streets. A stone with good resistance to impact from motor vehicles is required and the stone must be finished so that no sharp edges remain to damage tires. Slate and easily split varieties of sandstone (such as bluestone, a dark-colored, dense sandstone that splits readily) are used for flagging and similar paving purposes. Slabs may be rectangular and set in regular designs or they may be irregular in shape and set in random patterns. Thin veneer slabs one-fourth to one-half inch thick may be used to surface concrete pavements or thicker slabs may be used without concrete backing. Soft, uniform, fine-grained slate from Lehigh and Northhampton Counties, Pa., is the most widely used blackboard slate in the world.

Because of their smoothness, uniformity, performance, and attractiveness, slate blackboards are generally regarded as superior to all other types of blackboards now in use. School slates were once common in America, but their use has greatly declined. As they are small, their manufacture permits utilization of the smaller pieces many of which would otherwise be wasted. School slate is similar to blackboard slate, and production is largely confined to the same area.

Because sandstones consist of grains of exceptional hardness, they are used as abrasives. Grindstones are made of sandstones that are cemented to such a degree that they not only cut or grind steel readily but also wear fast enough to prevent glazing of the wheel surface. They have been replaced extensively by wheels made of silicon carbide and other manufactured abrasive materials. Stones for grinding wood pulp (pulpstones) were made in large quantities in past years, but synthetic products have replaced all but a small fraction of them. Scythestones, whetstones, and even razor hones can be made from sandstones; however, most of them are now made of synthetic stone. An extremely fine-grained silica rock, novaculite, still finds some use as a honestone.

Quartzites are sometimes employed in reducing ores or other mineral products to fine powders in tube or ball mills. They are used in two ways: (1) As linings for the tube mills and (2) as balls that reduce the mineral matter by impact of their tumbling action as the tube slowly rotates. Both liners and balls are so much harder than the mineral to be treated that they are worn slowly, whereas the mineral or ore is reduced to a powder more or less rapidly.

Smooth-finished slate with high electrical resistance finds use in switchboard panels. It must be free of magnetite and other low-resistance minerals and cutting and drilling it should not cause scaling. Thin, smooth sheets of slate are the premium material for billiard table tops.

Surface plates for mounting optical and electronic instruments are a specialized use for diabase, basalt, gabbro, and also granitic rocks. They

consist of slabs from 4 inches to 3 feet in thickness and ranging in size from 12 by 18 inches to 45 by 5 feet. The surface of the plate must be so flat and uniform that tolerances for uneveness range from 0.002 to 0.00002 inch. The producing companies may prepare them with tolerances ranging from 0.002 to 0.007 inch; the more precise surface finishing and calibration is accomplished by the surface plate dealers. Exacting millwork is required in making these products. Stone for such use must be extremely rigid and of uniform hardness and texture, although slight color variations are not detrimental. Diabase is regarded as a superior stone because, with the absence of free quartz, the constituent minerals have about the same hardness. This is favorable for attaining the desired precise surface uniformity.

Because of their high melting point (about 3,000° F), certain sandstones, sometimes called firestones, are used for refractory purposes. Blocks of carefully selected sandstone--usually from the lower beds in the Ohio quarries and particularly the exceptionally deep ones at Amherst--are used in places where high temperatures and severe abrasive action are encountered. They are used to line bessemer converters, soaking pits, blast-furnace ladles, and furnace arches and walls where acidic linings are required.

A very dense, extremely fine-grained, homogeneous limestone is sometimes used by lithographers for making etched plates although in recent years metal plates have largely replaced the stone variety. In addition there are miscellaneous uses for stone almost too numerous to mention, such as slate, sandstone, and soapstone for tubs, sinks, and tanks, soapstone furnace blocks, and sanitary slate for urinals.

CHAPTER 5.--SUBSTITUTE AND ALTERNATE MATERIALS

For almost any use one cares to name, dimension stone products are called on to compete with one or more alternate substances which, it is claimed, can do the same job as natural stone--and do it either less expensively or do it better. In some cases, the test of actual use over a long period of time has proven the validity of the claims made for some substitutes, and the original stone product has been driven wholly or entirely from the market. Examples of such instances are the replacement of stone paving blocks or cobble stones by portland cement concrete and bituminous concrete, manufactured abrasives in place of natural abrasive stones, and etched metal plates which are driving stone from popularity in the lithographers art. In other instances, the new substitute made inroads into the use of the natural stone product until time and nature showed that stone had certain advantages or inherent properties that still justified its use. Such items include slate blackboards, natural stone road curbings, and cemetery monuments. In other cases, such as exterior building stone, the original stone form was displaced and then the natural stone industry adjusted by developing newer forms suitable for the new construction methods, successfully reclaiming some of the ground previously lost to steel and concrete. But to this day, alternates or substitutes remain a Sword of Damocles, constantly reminding the industry that prices and quality of product must stand comparison with other eager suitors for the buyer's dollar.

Building stone must compete to a great extent with concrete, glass, brick, stainless steel, aluminum, porcelain enameled steel, wood, and plastics. For almost every use there is a substitute or alternate material. The initial cost of installing most of these alternate materials is lower than that of stone, but stone is still preferred for the more dignified buildings where its architectural adaptability, permanence, low cost of upkeep, and prestige are of prime importance. Today thin stone veneers and panels cover increasing areas of building interiors and exteriors but, because it is used in much thinner sheets, the weight of stone used has not gained in proportion. Value by unit weight, of course, increased as thinner stone panels require more machining and labor. However, per square foot of surface exposed, stone costs have actually become more competitive because the thickness of stone is generally about seven-eighths of an inch instead of the foot or more previously used. Even here, however, there is competition from thin panels of plastic, glass, metal, or exposed aggregate concrete. Many of the alternates may present problems involving matters such as fire resistance, weathering failure, resistance to lateral or ultimate load, and insulating efficiency. Imitation ashlar veneer and flagging is also a popular market item. Made of concrete, it is colored and precast to resemble natural sandstone products.

Slate, marble, or other stone chips or dust combined with a resin binder have emerged as a new competitor to dimension stone in the decorative arts. Table tops, lamp bases, ashtrays, countertops, interior wall panels, and other items are made of such materials under trade names using prefixes such as "cultured," "artificial," "synthetic," "cast," or "manmade" stone. Sometimes confusion occurs in the buyer's mind, particularly if the salesman stresses the noun such as "marble" or "slate" and forgets to explain the adjective. Generally speaking, of course, an item made of genuine stone is more costly than the same item made synthetically. Questions such as quality, prestige of natural stone, and aesthetic value must be weighed against price differential in deciding which item is the best value. Each person weighs such factors differently and so both types of product find a market.

Slate has to meet competition from many sources. As a roofing material, alternates such as granule-coated asphalt shingles, sheet metal, wood shingles, asbestos-cement shingles, tiles, rolled roofing, and built-up roofing are available. For blackboards it competes with colored glass, porcelain-enameled steel, and special painted surfaces. For electrical panels, marble, soapstone, and plastics are in competition, and for other structural uses, marble, granite, limestone, sandstone, and concrete products are readily available. Even for billiard table tops plastic substitutes have been introduced.

The introduction of memorial garden-type cemeteries, where memorial stones have been replaced by low bronze markers, temporarily reduced the growth in demand for monumental stone. However, a compensating demand by such gardens for large monumental theme stones and sculptures and the natural population growth has offset this factor so that both stone and bronze plaque coexist for such use. In traditional cemeteries, stone remains unchallenged by alternates or substitutes although style and taste changes have shifted to smaller, less ostentatious memorials. An interesting reactionary trend has been noted in the monument field. During winter months, in some States, low

bronze markers are buried in snow so that the memorial plot is difficult to locate. Some people, after experiencing this difficulty, decide that the traditional upright stone monument does have certain points in its favor, after all.

Similarly, concrete curbing, though cheaper to install than natural curb stones, has shown a tendency to crumble under repeated impact from vehicular traffic and to have less resistance to adverse effects from anti-icing road salts. As a result, concrete curbing has a maintenance cost considerably higher than a good granite curb stone. Some highway departments after abandoning stone curbs, returned to it for use in localities such as intersections where impact may be frequent.

CHAPTER 6.--RESOURCES AND GEOGRAPHIC DISTRIBUTION OF DEPOSITS

Rock, suitable for use as dimension stone, is almost ubiquitous in its geographic distribution. Dimension stone of one variety or another is almost always available within reasonable distances. Few large areas are totally devoid of formations that will yield blocks for major construction, though the choice of rock types and rock quality may be greatly restricted. Outwash plains, filled valleys, coastal plains, deltas, fans, and similar alluvium-covered areas are about the only places where dimension stone resources may be absent.

The geologic history of a region predetermines the various rock types that may occur in it. Classes of commercial stones fall into two broad groups as far as geologic history and geographic distribution are concerned: Crystalline rocks, including both igneous and metamorphic, and noncrystalline rocks, those of sedimentary origin. There are rare exceptions that prove the rule. For example, granites or marbles may occur in predominantly noncrystalline areas or small sedimentary basins may occur in crystalline rock areas.

It is not feasible within the size of this report to discuss the distribution of lithologic provinces over the entire world, but the major lithologic provinces in the United States can be rapidly summarized. In crystalline areas the popular commercial stones are granites, marbles, quartzites, slates, basalts, and greenstones; in noncrystalline areas the most widely used stones are limestones, sandstones, conglomerates, and basalts. Within a lithologic province not all rocks of commercial interest may be disseminated over the entire province. Some, for example marble, may be abundant in one part of a province and entirely absent in other sections. From east to west, five broad lithologic provinces may be delimited from inspection of geologic maps (fig. 4)

Province 1.--This province consists of the sedimentary strata of the Atlantic and Gulf Coastal Plain. Relatively young sediments, formations of consolidated rock that yield usable stone are relatively scarce. Except for the porous shell limestone (coquina) of Florida only the Cretaceous limestones near the inner edge of the province have provided usable stone with the notable exception of the rather poor Aquia Creek sandstone of eastern Virginia. This is the province most deficient in building stone due to its basically

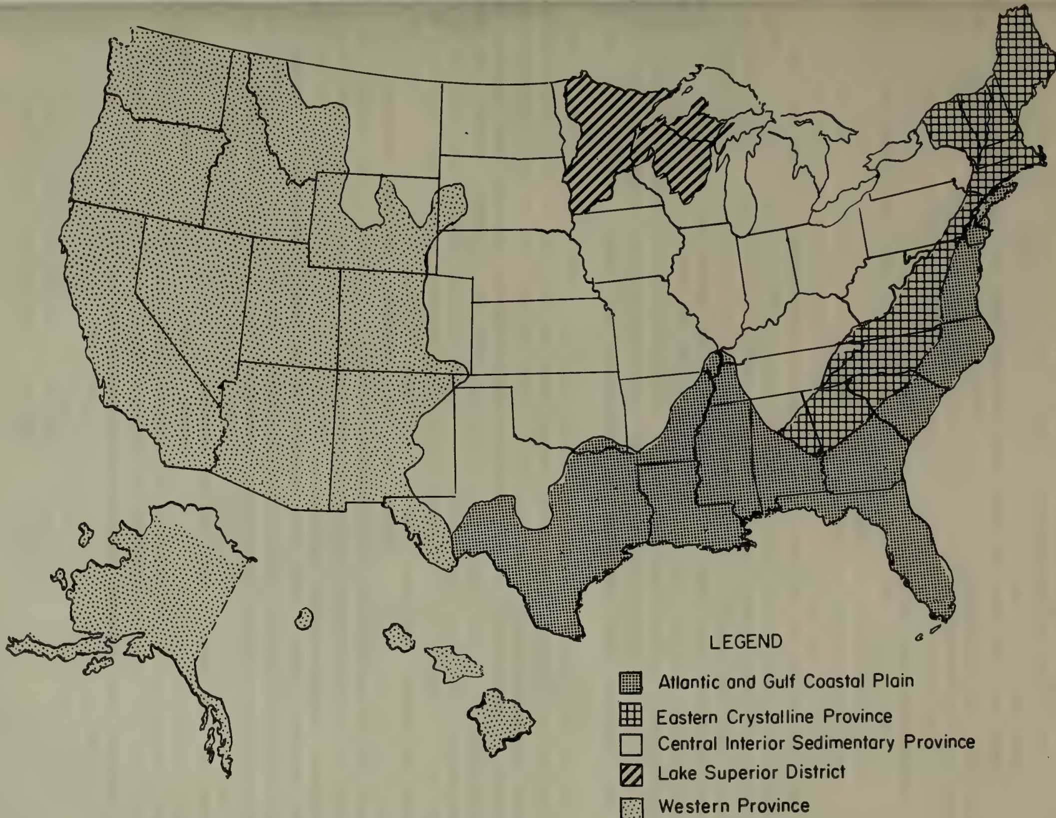

FIGURE 4. - Major Lithologic Provinces of the United States.

alluvial character and the dependence upon brick and wood construction in the period before good transportation is apparent.

Province 2.--The Eastern Appalachian or more properly the Eastern Crystalline Province includes not only the Appalachians, but also the Piedmont, Adirondacks, New England, and local sedimentary basins of Triassic and Carboniferous rocks. Geologically the province is characterized by a wide variety of crystalline rocks. Because of its geographical contiguity to major historical dimension stone markets, it has in the course of time produced perhaps 90 percent of the crystalline stone of this country. Granitic rocks, marble, slate, and greenstones have been the principal crystalline products. Granitic rocks have been produced in many of the States, most notably in New England, Georgia, South Carolina, and Maryland. Marble production has centered in Vermont, Tennessee, North Carolina, Georgia, and Alabama. Slates and similar fine-grained, cleavable crystallines have had production centered in Maine, Vermont, New York, Pennsylvania, Virginia, and North Carolina. Much greenstone and other miscellaneous stone is quarried in Virginia. Several sedimentary basins or "inliers" in the province have produced basalt, sandstone, or conglomerate, notably in Virginia, Maryland, Pennsylvania, New Jersey, New York, Connecticut, and Massachusetts. In northern Maine, Paleozoic sedimentary rocks occur including large amounts of limestone and graywacke sandstone but they have not been exploited or evaluated for dimension stone.

Province 3.--The Central Interior Sedimentary Province includes a vast expanse of sedimentary strata extending from the Rockies to the Appalachians. These strata comprise the bedrock beneath the plain States, the Cumberland and Alleghany plateaus and the valley and ridge sector of the western Appalachians. Crystalline rocks are almost entirely absent except for small areas in Montana, South Dakota, Oklahoma, and Missouri. Limestones and sandstones (including quartzitic varieties) are the basic dimension stones accounting for about 90 percent of these types produced in the United States. The most famous limestone source has been the Indiana oolitic limestone district (Bedford-Bloomington area) utilizing the Salem limestone. Other notable commercial limestones have been the Niagara (dolomitic) in northern Illinois and southern Wisconsin, the Burlington in western Illinois and adjacent areas, the dolomitic limestone near Kasota and Mankato, Minn., and crystalline limestone, classified commercially as marble, from the Carthage district of Missouri. Actually suitable limestones occur throughout the province. Sandstone is similarly of ubiquitous distribution with Ohio, Colorado, Pennsylvania, Tennessee, and New York as the leading sources. The stone ranged from true blocky sandstones in Ohio, to thin-bedded bluestone in New York and Pennsylvania, through quartzitic stone in Colorado and Tennessee. A previously mentioned few scattered occurrences of granite have been noted. Southeast Missouri and southwestern Oklahoma are sources of granite monumental and building stone.

Province 4.--The Lake Superior District is underlain by crystalline rock and has been an important source of granitic-type stones, particularly in Minnesota and Wisconsin. Production ranges from true granites through to black granites (gabbro) and rhyolite.

Province 5.--The Western Province consists of a large area of intermixed crystalline and sedimentary rocks. Both types are widespread, and so complex is the intermingling and distribution that a further breakdown is not practical here. Granites, sandstones, limestones, slates, marbles, and miscellaneous stones are all produced within the province. Resources of suitable formations are practically inexhaustible and broadly distributed, but lack of development and demand for building stone in much of the area has not favored widespread development of the dimension stone industry. To date Colorado, Arizona, and California have supplied most of the indigenous production to augment stone imported from outside the province.

Domestic Resources

The following descriptive sections are not intended to be comprehensive listings of all stones ever used domestically. They are intended to encompass the most significant or noteworthy ones. For complete reviews and technical discussions, the serious reader should consult the numerous reports available including those of the various State Geological Surveys and the United States Geological Survey (3, 6, 21, 22, 24, 39, 40, 49, 74, 77, 86, 87, 90, 92, 96, 101, and 107). Almost every State has, at one time or another, cataloged the stone resources in their jurisdiction. The State Geologist is the best source of such information, both published and unpublished file reports.

Limestone

Limestone occurs in every State, but a relatively small number of deposits are suitable for and furnish the bulk of the domestic dimension limestone production. In 1966, dimension limestone was produced in 24 of the States (fig. 5).

Alabama

Limestone occurs in a belt about 20 miles long in Franklin County in the Bangor Formation of Mississippian age. Gray to buff commercial stone lies in beds 20 to 25 feet thick. It is oölitic in texture (resembling fish roe) and consists of about 97 percent $CaCO_3$ and a small percentage of magnesium carbonate. An underground mine and an open quarry are near Rockwood, where the stone is fabricated in a large mill. It has been sold widely for many years for rough architectural and dressed building stone.

California

Few extensive limestone deposits comparable with those in many of the midcontinent or eastern States occur in California. Most of the California deposits are irregular bodies of variable magnesium content. They have been subjected to varying degrees of metamorphism and for the most part should actually be classified as marble.

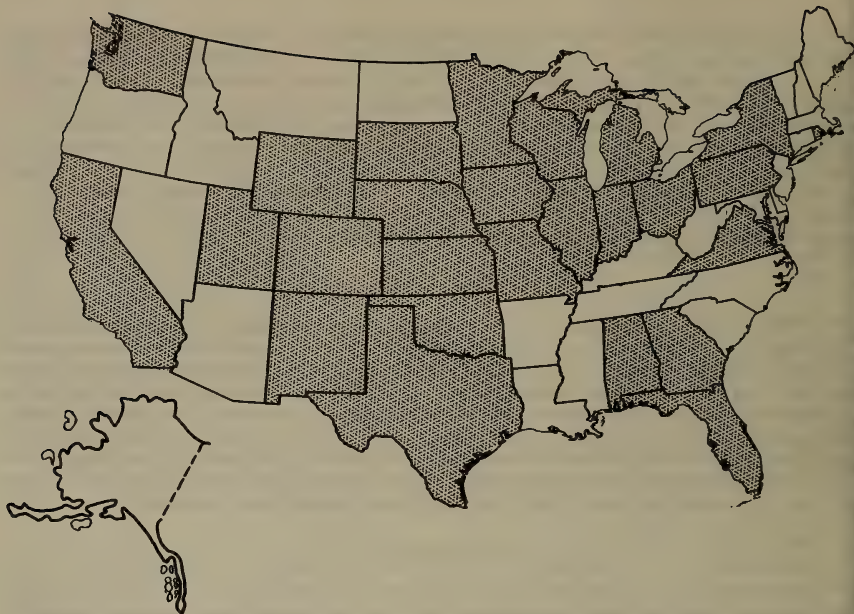

FIGURE 5. - States Producing Dimension Limestone in 1966.

Colorado

Colorado limestone deposits' are in two groups--an eastern division forming a belt immediately east of the Front Range and a second division lying west of the range. Limestone of the eastern division extends from the north of Fort Collins to the middle of Douglas County, passing a little west of Denver and continues with interruptions through several south and southeaster counties. Widely used for crushed and broken stone products, the deposits have not been used for dimension stone production to a very great extent. Th largest operations are in Pueblo, Fremont, Larimer, El Paso, and Caffee Counties. Some of the limestone west of the range are high quality, but their location has discouraged development.

Florida

Limestones are plentiful in Florida, but many of them are the soft, friable shell types. The Tampa limestone of the west-central counties is fairly hard and compact. Coral and oölitic limestone form the foundation of the Key and border the east side of the Everglades.

Georgia

The commercial limestones of Georgia are confined chiefly to the northwestern counties--Polk, Dade, Bartow, Fannin, Gilmer, Cherokee, and Pickens, and the extreme southwestern part of the State.

Illinois

Limestone and dolomite deposits of potential commercial value occur in scattered areas along the northern, western, and southern boundary counties. Presently, only rubble and flagging is produced.

In Union County, the Warsaw-Salem Formation, which is of Lower Mississippian age, provides a limestone which is being quarried primarily for housing veneer. The stone is nearly 99 percent $CaCO_3$ and consists of dark gray grains of calcite in a light gray to white matrix of finely divided fossil fragments. The calcite grains occur in layers thus giving the stone a banded appearance when cut at right angles to the bedding or a bloched pattern when cut with the bedding. The stone has a pleasing color and texture, is easily worked, and is weather resistant. The housing stone is marketed in Illinois while some block and cut stone has been sent to neighboring States, and to St. Louis in particular.

Indiana

Indiana is the chief source of building limestone in the United States; it furnishes about 34 percent of the total sawed and cut stone. The Salem limestone of Middle Mississippian age is quarried primarily in Lawrence and Monroe Counties, where thicknesses of 40 to 80 feet are common. The commercial stone is nearly 98 percent $CaCO_3$, consisting of microfossils and shell fragments deposited under conditions similar to those which exist off the coast of Florida today. The stone is quarried in large, sound, uniform textured blocks which are either buff or gray. Because of the stone's workability and durability, it has been shipped all over the United States and parts of Canada; however, the primary markets are in the States from Illinois to New York plus the District of Columbia. The State has several of the largest and best equipped quarries and stone finishing plants in the United States (fig. 6).

Iowa

High calcium and dolomitic limestone resources in Iowa are large and widespread throughout the State.

Dimension limestone production during 1966 was reported from Jones and Dubuque Counties. The dimension stone produced was chiefly irregular-shaped stone for facing buildings and cut stone, including ashlar. A lesser amount of dimension stone was produced for rubble, house stone, veneer, sawed stone slabs and flagging.

FIGURE 6.—Indiana Limestone Quarry. (Courtesy, Indiana Limestone Co.)

Dolomite and dolomitic limestone in Niagaran Series of Silurian age rocks and the Mohawkian Series of Ordovician age rocks have furnished good grades of building stone over wide areas.

Kansas

Permian limestones in the Flint Hills region are the source of the most popular commercial building stones of Kansas. They include the buff-to-tan Fort Riley limestone quarried extensively in many localities in the past and currently quarried near Silverdale, Cowley County, and in the vicinity of Junction City, Geary County; the "Onaga" (Funston) limestone similar in texture to that of Fort Riley and quarried in Pottawatomie County; and the buff-to-white Cottonwood limestone quarried primarily in Chase County.

In north-central Kansas, the brown-streaked tan "Fencepost" limestone bed of the Greenhorn (Cretaceous) rock formation has been utilized extensively, not only for buildings, bridges, and other structures, but also for fenceposts.

Kentucky

Kentucky is underlain with the same limestone formations that occur in Illinois, Indiana, and Ohio, and they appear in many eastern, southeastern, central, north-central, and western counties.

Michigan

A small quantity of dimension limestone has been produced in Michigan in recent years. About two-thirds of the stone has been used for rubble, while a third has been utilized for building purposes. Companies reporting dimension stone production are located in Eaton, Huron, and Presque Isle Counties, all in the lower peninsula. Although Michigan is a major producer of limestone, nearly 38 million tons in 1966, less than one percent is classified as dimension stone.

Minnesota

Virtually all of the Minnesota limestones are dolomitic. The Oneota dolomite of Ordovician age furnishes most of the building limestone. It has been quarried for many years at Mankato, Blue Earth County; Kasota, LeSueur County; and Winona, Winona County.

Early use of this stone was for heavy construction and bridge building. Concrete replaced stone for these purposes and with the development of efficient methods for milling stone, the Oneota dolomite is currently used for interior and exterior cut stonework.

The Mankato-Kasota district stone varies in texture and color. The Kasota stone has been recrystallized to such an extent that it is sometimes called marble. The stone ledges vary in color; some are buff, cream, pink, yellow, gray, and red. The yellow and pink varieties are popular for interior trim and decoration. The various colors, when used at random, blend to

produce beautiful stonework. The gray to white Winona stone is quarried high on the Mississippi River Bluffs. Some beds are porous and are marketed as travertine. The magnesium content is high enough to class it as a dolomite.

Missouri

Limestone outcrop over nearly half of Missouri and are more extensively quarried than any other rock. Some limestones are excellent for building purposes while others, on account of impurities or structure, are worthless. The Burlington is the most important of Missouri limestones, and the best quality of Burlington stone occurs in the southwestern part of the State. The largest quarries are in Carthage, Jasper County. The Statehouse at Jefferson City is built of Carthage limestone. The Burlington of southwestern Missouri compares favorably in strength and appearance with the best limestones of the United States. The Burlington crops out in a wide belt in northeastern Missouri to southwestern Missouri, excepting in the extreme southwest counties where it seems to be absent. The rock is generally described as gray, bluish-gray, buff-gray, and white. Some stone takes a good polish and is commercially classified as marble.

Nebraska

The more important limestones of Nebraska are those of Pennsylvanian age in the southeast and the Niobrara Formation along the Missouri River Valley.

New York

Limestones occur extensively in New York from the shores of Lakes Erie and Ontario to the Hudson River Valley. Numerous limestones of varying composition and character occur in the thick Paleozoic stratigraphic sequence.

Ohio

Limestones underlie about one-third of Ohio. The bedrock of western portions of the State represents eastern extensions of the formations widely quarried in Indiana. In addition, scattered deposits of limestone are found in eastern portions of the State. At present dimension limestone is produced near Bloomville and Flat Rocks, Seneca County, and near West Milton, Miami County.

Oklahoma

Limestones occur in northeastern, north-central, southeastern, and south-central Oklahoma. The stone is predominantly high-calcium in character with lesser magnesian limestone. The formations range from high-purity to those that are quite cherty.

Pennsylvania

Large quantities of rough building limestone and rubble are produced at various points, particularly in southeastern counties.

Rhode Island

A crystalline limestone is quarried in the valley of the Blackstone River. Technically the stone is more properly a marble but has been historically termed a limestone in the local trade and has been so classified in Bureau of Mines statistical operations.

Texas

In Tarrant County, Cretaceous limestone is quarried near Fort Worth for use as dressed building stone. In Gillespie County, Lower Cretaceous limestone is quarried near Grapetown community in the southern part of the county for use as rough construction, rough architectural, and dressed building stone, and as curbing and flagging stone. In El Paso County, Paleozoic limestone is quarried on the east flank of Franklin Mountains in El Paso for use as flagging stone.

At Cedar Park, Williamson County, a ledge about 30 feet thick provides a pale-buff to cream oölitic limestone which is quarried for building stone. Certain beds contain large fossils and are porous, resembling travertine. At Lueders, Jones County, a deposit of thin-bedded, light-gray and variegated limestone, harder than the Cedar Park stone, is quarried for building purposes.

Utah

For dimensional use, the Flagstaff limestone, quarried in Utah County, has been the leading limestone source in Utah. It crops out along the east flank of the Wasatch Mountains, on the Wasatch and Gunnison Plateaus, and in adjacent areas. An oölitic limestone known as "Manti Stone" and "Sanpete White" has been quarried for building use in Sanpete County.

Wisconsin

For several years Wisconsin has ranked third both in quantity and value of dimension limestone produced in the United States. The two largest producing districts within the State are (1) the Sussex-Lannon area in Waukesha County and (2) the area near Fond du Lac, Eden, and Oakfield in Fond du Lac County. Stone from the former deposit is a thin-bedded, gray dolomite containing about 51 percent calcium carbonate, 42 percent magnesite, 6 percent silica, and 1 percent alumina and iron combined. At the latter deposit, the stone is of a grayish white color with occasionally a slight amount of buff containing about 54 percent calcium carbonate, 44 percent magnesite, 2 percent silica, and less than 1 percent alumina and iron combined. Uses for dimension limestone produced in Wisconsin are house stone veneer, rubble and rough construction, flagging, cut and sawed stone, and rough architectural purposes.

Sandstone (Including Quartzite)

Sandstones suitable for use as dimension stone occur in many deposits in the United States. However, because of production and market factors, in the

numerous localities where suitable stone is available, only a relatively few sandstones are worked (fig. 7).

In 1966, Ohio accounted for about 35 percent of the tonnage and 50 percent of the total value of dimension sandstone sold in the United States. Its products are chiefly cut and dressed stone.

In the discussion of deposits, the States are considered in alphabetical order. Because of the vast number of sandstones which have been exploited at one time or another (many of them of local economic significance only), descriptions of only the more noteworthy localities are included.

Alabama

Sandstone ranging in color from pink to buff and brown has been quarried for structural use and flagging at Oneonta, Blount County. Rough architectural stone and flagging have been produced at Fort Payne, De Kalb County. A quarry in Marshall County produces rough architectural building stone.

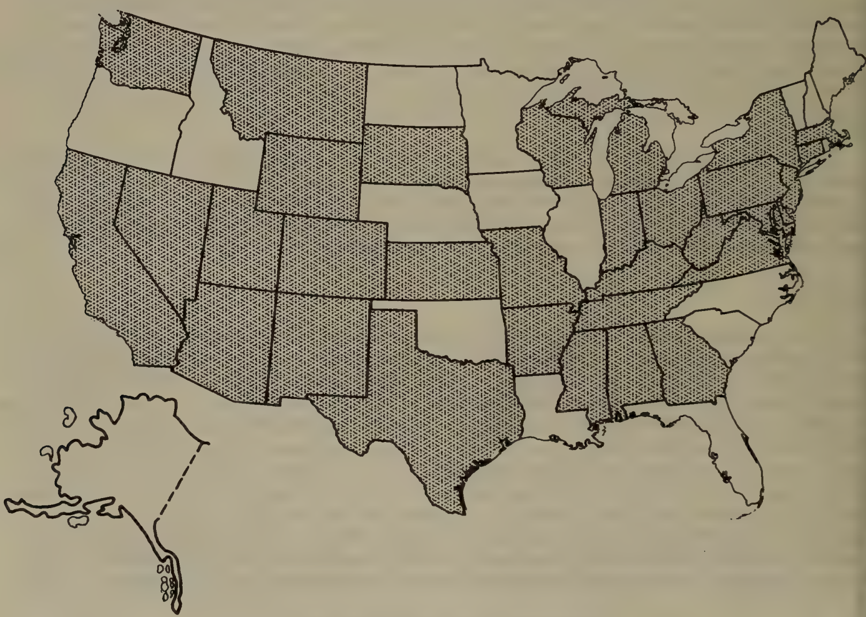

FIGURE 7. - States Producing Dimension Sandstone in 1966.

Arizona

At present production from the Coconino sandstone dominates the industry. It is a well-cemented red, pink, or white aeolian sandstone of Permian age. Although worked as far east as Holbrook, and as far west as Seligman, the town of Ashfork is the center of production. Sandstone from the Triassic Moenkopi Formation has been used extensively for construction in the northern part of the State. The Permian DeChelly sandstone is also reported to offer potential as a dimension stone.

Arkansas

Practically unlimited quantities of sandstone exist in the highland area of Arkansas. Sandstone dimension stone is produced from two districts. The larger production comes from the Logan-Johnson County area which ships substantial tonnages of attractively colored, cut blocks and slabs of Hartshorne sandstone throughout the midcontinent region. A smaller district is located near Batesville, Independence County, where appreciable amounts of beautifully colored and banded Batesville sandstone blocks are produced.

California

Sandstone crops out predominantly in the Coast Ranges of northern and central California and the Transverse and Peninsular Ranges of southern California. Almost all of the dimension sandstone has been produced from Cretaceous Formations.

Colorado

Sandstones occur in abundance throughout Colorado. Red, pink, and variegated sandstone of the Lyons Formation, occurring near Lyons in northern Boulder County, is marketed chiefly as broken stone for wall veneer, for various other architectural uses, and for flagging. This quartzose sandstone is thin-bedded and more than 300 feet thick. It splits easily along the bedding planes, and sheets 4 to 5 feet wide and only 2 or 3 inches thick are often quarried. At Berthoud and other points in Larimer County, rubble, flagging, rough construction stone, and rough, sawed, and dressed architectural stone are produced from the same formation. Larimer County is now the major source of dimension sandstone in the State. Canon City in Fremont County, where Triassic red beds crop out, had been an important center of production during past years. Small amounts of Dakota sandstone have been quarried in Gunnison County for grindstone manufacture, but recent output of dimension sandstone has been mostly from Boulder, Larimer, and Mesa Counties.

Connecticut

Sandstones occur extensively in the Triassic red beds of the central Connecticut Valley. The belt of Triassic strata extends northward from New Haven into Massachusetts with an average outcrop width of 20 miles. The sandstone was worked at Portland, Conn., from the mid-17th century until the depression years of the 1930's. The stone was reddish brown to light milk

chocolate in color because of ferric oxide coatings on quartz grains and colored clay minerals in its cement. It was highly fashionable during the last decades of the 19th century when New York and Boston gentry preferred brownstone fronts for their townhouses. The stone was convenient to quarry, lying almost flat with interbedded fine shales forming useful bed seams and two systems of vertical joints at right angles to each other. The quarries were practically at tidewater on the bank of the Connecticut River for easy loading on barges for transport to New York or Boston. At the height of operations, 800 men, 200 oxen, and 60 horses were employed in the quarries. Gradual change in tastes to a preference for lighter colored stone, coupled with poor building practice, brought the brownstone into disfavor. Many builders set thin sandstone blocks on end as a veneer over brick. Set thus, with bedding planes vertical, the rock spalled readily in frosty climates and produced a ragged, pocked surface. When this sandstone was properly used, as in some of the older buildings of Wesleyan University in Middletown, Conn., it was a handsome and durable construction material. Thin-bedded stone called sandstone is quarried for construction and flagging near Sterling-Killingly, Windham County.

Georgia

Paleozoic sandstone crops out in the northwestern part of the State. In Pickens County it is quarried for flagging and rubble.

Indiana

Seven counties in south and south-central Indiana have sandstone production. The primary product is veneer stone architectural work on buildings; most of the remaining production is rough or irregular stone used in construction work. The stone is a medium-grained clear quartz with hues of red, yellow, and brown coming from the iron in the cementing materials. More than half of the stone used in architectural work comes from Lawrence County. Quartz conglomerate is quarried for refractory use in Martin County.

Kansas

Sandstone of Pennsylvanian age is quarried for dimension stone in Bourbon County near the eastern boundary of the State.

Kentucky

Architectural stone and flagging have been produced at Lewisburg and Russellville, Logan County, in southwestern Kentucky. Rough architectural stone has been shipped in relatively small quantities from Livingston County. During 1960, rough and dressed building stones were produced, and in the past, rubble and flagging have been produced in northern McCreary County. During 1965, a small quantity of dimension sandstone was produced in Christian County

Maryland

Quarries in the red Triassic sandstones of western Maryland that were operated many years ago have been abandoned. There has been recent production from beds of quartzite, probably of Cambrian age, occurring near Butler in western Baltimore County. Sandstone is quarried for dressed and sawed architectural stone, rough construction stone, rubble, and flagging at Grantsville, Garrett County.

Massachusetts

The Triassic brown sandstones of the Connecticut River Valley were worked extensively many years ago. Currently they are quarried only at East Longmeadow, Hampden County, where one long-established operator manufactures dressed stone on a moderate scale. Stone is obtained from two high-grade beds, one 10 feet thick and the other 14 feet thick.

Michigan

Light-colored sandstones of Carboniferous age occur both in southern Michigan and in the upper peninsula. Quarrying is centered chiefly in an area near Napoleon (Jackson County) and Arnheim (Baraga County), where rubble, dressed stone, rough construction stone, and flagging are produced. Only one-eighth of the output, which totaled less than 8,000 tons in 1966, was used for building purposes or flagging.

Minnesota

At New Ulm, Nicollet County, quartzite is quarried for filter blocks for water and sewage treatment plants. Near Jasper in Rock County, quartzite is produced for tube mill liners, grinding pebbles, and riprap.

Missouri

The most important sandstones of Missouri are those of Pennsylvanian age. Some large and well-equipped quarries are located on the sandstones. Two of the largest quarries are at Warrensburg. The Warrensburg stone is used for building purposes and for the manufacture of grindstones. Some of the stone is sawed and used for sidewalk purposes. Several important buildings in St. Louis and Kansas City, Mo., and Omaha and Lincoln, Neb., and other places have been constructed of sandstone from the Warrensburg quarries. The Pennsylvanian sandstones are of various qualities and weathering may so affect the rocks near the surface as to render them valueless. All those deep in the quarries are in excellent condition.

Montana

Sandstone and quartzite are quarried for dimension stone at two quarries near Nichart, Cascade County. Quartzite has also been quarried near Thompson Falls.

Nevada

Sandstones in red, yellow, pink, and various other colors are quarried near Crystal, Goodsprings, and Jean, Clark County. They are marketed in the form of dressed stone, rough building stone, and flagging. Sawed and dressed stone is produced in Humboldt and White Pine Counties.

New Jersey

Brownstone of Triassic age, similar to that of Connecticut and Massachusetts, was formerly worked in northern New Jersey. Currently, sandstone for construction and flagging is quarried near Lambertville, Hunterdon County.

New Mexico

The cream-colored Glorieta sandstone has been quarried near Lamy for use in Santa Fe. Dark-red, gray, and brown sandstones from west of Las Vegas have also been used to some extent.

New York

Many years ago, the largest sandstone quarries in the State were in the Medina Group of Orleans County in western New York but these quarries are now inactive. Sandstones now produced consist chiefly of bluestones of Devonian age which occur along the Hudson, Delaware, Susquehanna, and Genesee Rivers. Centers of production are, or have been, at Portageville on the Genesee River (Wyoming County) and near Masonville and South Unadilla on the Susquehanna River (Delaware County). Dressed stone, curbing, flagging, and sawed stone are produced in substantial quantities from these deposits. Bluestone is quarried along the Delaware River at East Branch, Deposit, Masonville, and Hancock in Delaware County and in Broome and Albany Counties. At one time, Kingston on the Hudson River (Ulster County) was an important point from which shipments of bluestone were made. Quarrying began as early as 1840 but output in this area is now small. Sawed stone is produced near Ithaca in the Finger Lake District of Tompkins County, and rough architectural stone is produced at Burke, near Malone, Franklin County, in northern New York.

Ohio

Gray and buff sandstones occur abundantly in Ohio--the leading producing State--and are quarried in three principal areas. The most productive region, a prominent source of building stone since the latter part of the 19th century is Lorain County, about 25 miles west of Cleveland. The largest sandstone quarries in the United States are in the Berea Formation near Amherst and Kipton in Lorain County. The Buckeye quarry, of more than 240 feet, is the world's deepest sandstone quarry. The No. 6 quarry, having produced more than 470 million cubic feet of dimension stone, is the world's largest sandstone quarry. As early as 1832 these Berea sandstones were quarried on a commercial scale. A full range of sawed and dressed building stone, house veneer, curbing, abrasive and refractory stone, and flagging is fabricated in large mills adjacent to the Amherst quarries. At Amherst there are nine active quarries

and four finishing and fabricating plants, which, together, employ more than 300 people. An appreciable portion of the refractory stone is produced in crushed form.

A second important region is in east-central Ohio near Glenmont and Killbuck (Holmes County), Dover (Tuscarawas County), and Fresna (Coshocton County where Mississippian sandstones occur in many places. Sawed and dressed stone as well as house veneer and flagging in a variety of colors are produced from active quarries near Glenmont, Killbuck, Stillwell, Spring Mountain, Cavallo, New Castle, and Layland.

The Cuyahoga Formation, also of Mississippian age, is quarried extensively in a third region near McDermott, Scioto County, at the southern border of the State. Sawed and dressed building stone and flagging are the principal materials manufactured. Because the stone is exceptionally fine-grained and uniform, its products include slabs for vaults and covers, laundry tubs, sinks, tanks, and similar products. Sandstone is quarried at times in several other counties.

Oklahoma

Sandstones of Pennsylvanian age are quarried at Locust Grove, Mayes County, and near Henryetta, Okmulgee County, in northeastern Oklahoma. The principal products are dressed building stone and veneer. Quarries are operated at times in the Cretaceous sandstones near Hugo, Choctaw County, and Moyers, Pushmataha County, near the southeastern corner of the State.

Pennsylvania

Although not the largest producing State, Pennsylvania has the greatest number of production centers. Bluestones are quarried in the northeastern counties, chiefly at Harford, Rush Township, Springville, Susquehanna, Montrose, and Kingsley (Susquehanna County) and at Sterling and Honesdale (Wayne County). Flagging is the principal product; smaller quantities are used for rough construction and rubble. Sandstones, chiefly of Triassic age, are quarried extensively in the southeastern counties adjacent to the Philadelphia metropolitan district. Quarries are operated at Media (Delaware County) at Malvern, Avondale, and West Grove (Chester County) at Norristown and Glenside (Montgomery County), and at several locations in Bucks County. Flagging and rough construction stone for house veneer are the principal products. Quartzite of Cambrian age has been quarried for use as building stone in Carbon County east of White Haven. Quartzite in shades of green, gray, and purple has been produced for house veneer and flagging in Cameron County. Dimension sandstone as curbing stone, irregularly shaped rough construction stone, and rough architectural blocks was recovered in 1965 from quarries near Austin, Wharton, Roulette, Condersport, Gold, and Bark Shanty in Potter County.

Other areas of production are in the Pittsburgh region near the western border. Rough building stone and flagging are quarried at Belle Vernon (Westmoreland County), Jefferson and Elizabeth (Allegheny County). Production is recorded at times from several other counties.

Tennessee

Production from Cumberland County increased rapidly starting in 1951, peaked in 1955, and has decreased since 1958. In spite of the decrease, Tennessee is still one of the leading producer States. Several companies operate quarries in the Crossville sandstone of Pennsylvanian age that abounds near Crab Orchard and Crossville in Cumberland County. Crossville sandstone is a fine-grained, thin-bedded, extremely hard and durable sandstone, which is so strongly cemented by silicas that it is commonly referred to as quartzite. The products are chiefly architectural building stone and flagging. As building stone, the material is used for a wide range of products, including stone for the entire walls of buildings, or for trim, steps, floor tile, water tables, sills, caps, cornices, fireplaces, hearths, chimneys, and even roofing slabs. Quarries are also operated in some adjacent areas, such as in the vicinity of Sunbright (Morgan County), Jamestown (Fentress County), and Rockwood (Roane County).

Texas

In Parker County, Pennsylvanian sandstone is quarried near Millstaff for use as rough construction building stone.

Utah

Sandstone is the most widely distributed and widely used dimension stone resource in Utah. Greatest present production is from the Jurassic Nugget sandstone in Salt Lake, Summit, Wasatch, and Utah Counties. Other sandstones of good quality also are exploited in Washington and Summit Counties.

Virginia

A light-gray sandstone at Aquia Creek in Stafford County was used in the White House, the Capitol, and other early American Government buildings. It was the first U.S. building stone of more than local importance and was being shipped as far as Boston in 1820. Its poor weathering qualities brought it into disrepute, and it has not been quarried to any extent since 1840.

A thin-bedded quartzitic sandstone dipping at a steep angle occurs between Haymarket (Prince William County), and The Plains (Fauquier County). Some rough construction stone is quarried but the chief product is for flagging at The Plains.

Washington

Sandstone quarrying in Washington is confined almost exclusively to the vicinity of Wilkeson and Orting, southeast of Tacoma in Pierce County. Some dressed stone is produced but the chief output is rough architectural stone for house veneer.

West Virginia

Good-quality sandstone has been produced at several localities in Preston County. Until 1914, quite a bit was used for buildings in New York, Philadelphia, Washington, and other eastern cities. A small amount of dimension stone is still produced near Aurora.

Wisconsin

Sandstone was produced in Marathon, Sauk, and Wood Counties in Wisconsin during 1966. In recent years, production was also recorded from Clark and Portage Counties. Sandstone was last produced in Dunn County in 1956. Cut stone, flagging, rough construction, and rubble comprise the uses for dimension sandstone quarried in Wisconsin. Production is mainly from deposits of the Potsdam (Cambrian) age. Lake Superior brownstone was formerly quarried in Bayfield County but the operations are now inactive. In the past, sandstone from other areas throughout the State was produced for building material, largely for local use in foundation work. Stone from the quartzite deposits in Sauk County is sold in crushed and broken form rather than as a dimension stone.

Wyoming

Sandstone deposits are widespread in Wyoming. The most popular dimension stones have been Cambrian quartzites of Carbon County and the Carboniferous sandstones east of Laramie in Albany County.

Marble

Because most marbles are the result of regional metamorphism associated with diastrophism, they occur chiefly in mountainous areas. In the United States the most productive regions are the Appalachians, Rocky Mountains, and the Coast Ranges of the West. In 1966, marble was produced in 15 States (fig. 8).

Alabama

The principal marble belt of Alabama passes through southern Talladega and northern Coosa Counties. It is about 35 miles long and has a maximum width of 1½ miles near Sylacauga. The marbles range in geologic age from Middle Cambrian to Middle Ordovician. On the southeast, the belt is bordered by the Precambrian Talladega slate or phyllite, and, for most of its length on the northwest, by Ordovician Knox dolomite.

The best marble beds are 200 feet or more thick and dip about 30 degrees southeast toward the slate. Intense compression and folding are evident; consequently, definite systems of joints have been developed. In places irregular, radial, and closely spaced, joints result in a high percentage of quarry waste.

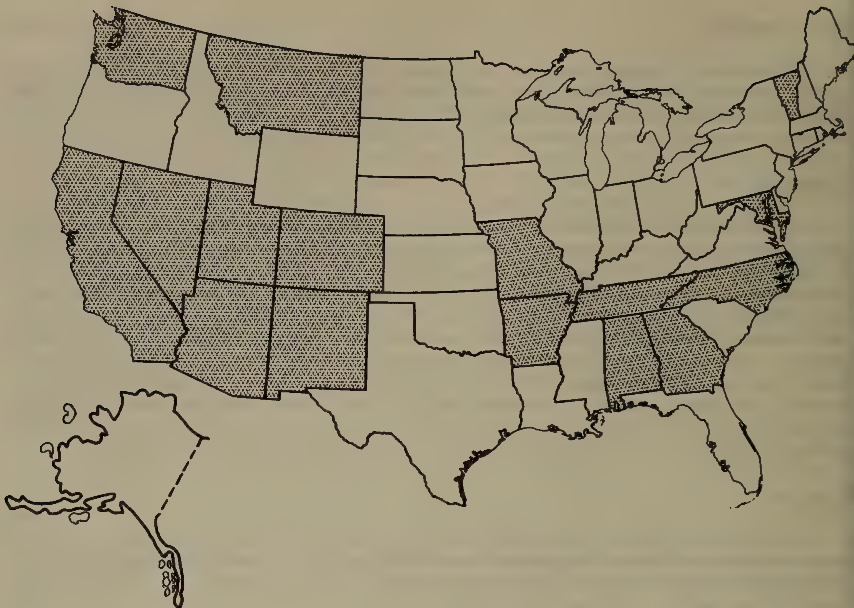

FIGURE 8. - States Producing Dimension Marble in 1966.

Most Alabama marbles are white, and some beds furnish pure, flawless material of statuary grade. Alabama marbles are somewhat finer grained than Vermont marbles and much finer grained than most Georgia marbles. Layers of light-green talc and schist give ornamental patterns or clouding to some varieties. Marbles from some beds are translucent. These marbles were used for the so-called transparencies in the roof of the Lincoln Memorial in Washington D.C. Porosity is low, averaging about 0.5 percent according to National Bureau of Standards tests, with a somewhat lower percentage for varieties best adapted for exterior use. The marble is notably pure, containing 98 to 99 percent calcium carbonate.

The most productive region is Gantts Quarry, Sylacauga, Talladega County, where large open-pit and underground openings have been made. At Gantts Quarry, diagonal jointing predominates; about 15 beds have been worked, each 4 to 11 feet thick. Because of differences in color and texture of the beds, several standard types are produced. In mills adjacent to the quarries, the marble is manufactured into finished products, chiefly for rough and dressed building stone and for dressed monumental stone.

Waste marble is ground into a very fine powder for use as whiting and as a constituent of such products as paint and stock feed.

A second large quarry is about three-quarters of a mile northeast of Gantts Quarry. Here, most joint planes parallel the dip and strike, but occasional diagonal joints result in much waste. Some beds are clouded; others are uniform and creamy white.

Alaska

Marble deposits, widely distributed throughout southeastern Alaska, were worked as early as 1902. Intermittent production and shipments to Pacific Northwest ports continued until the late 1930's with value estimated at $2 million. The bulk of the production came from Calder on Prince of Wales Island at Shaken Bay and from Tokeen on Marble Island in Davison Inlet. Other notable deposits occur on Dall, Long, and Revillagigedo Islands. The Calder quarry is on a bluff about 100 feet above sea level. Metamorphism of the original limestone probably was caused by the intrusion of a granite that lies northeast of the marble. The deposit is said to be large. Three types of marble were quarried: Pure white (the most valuable); blue-veined white; and light blue or mottled. The white marble ran more than 99 percent calcium carbonate. The Tokeen quarry furnished white, blue-black, and gray marbles.

Arizona

Occurrences of marble are numerous but scattered in Arizona. Most of the deposits can be grouped roughly into the following areas: Harquahala Mountains, Tucson region, Dragoon and Chiricahua Mountains. Most of the marbles are white or drab-colored but spectacular shades and patterns are found in the Dragoon Mountains. Highly ornamental onyx marbles occur northwest of Sonoita, Santa Cruz County, near Cave Creek, Maricopa County, at Mayer, Yavapai County, and 20 miles north of Globe, Gila County.

Arkansas

The Arkansas marbles are usually found in various shades of gray, although pink, chocolate, and black marbles are found at numerous outcrops in the White River basin.

The marble is used for building and house construction, for monuments, for interior decorating, flooring, electrical switchboards, table tops, washbasins, and statuary. Terrazzo, a flooring material, is made from the waste marble chips. Onyx marble, a banded variety of limestone, is used as an interior decorative stone, for statuettes, lamp shades and bases, and in jewelry.

Crystalline limestone or marble crops out over an area of 2,000 square miles in northern Arkansas. The beds usually have a workable thickness of from 25 to 50 feet and at some places are 155 feet thick.

The "Batesville" marble has been rather widely used and is usually cut into either small rectangular blocks for house construction, or large blocks for use in buildings. It is a gray stone and is produced from the Boone Formation near Batesville. Marble blocks are also quarried near Batesville from the St. Clair, Fernvale, Kimmswick, and Plattin Formations and shipped to Carthage, Mo., where several varieties and grades of stone are cut for interior and exterior use in buildings. Black marble suitable for interior use occurs in formations of Mississippian age in Independence, Cleburne, Stone, and Searcy Counties. Onyx marble is found in caves in north Arkansas.

California

Marble deposits are numerous in California. Deposits have been noted in at least 28 counties but most of them are small or inaccessible. In many places the rock is so shattered by earth movement that large, sound blocks are unobtainable. Marble of many colors has been produced near Lone Pine, Inyo County. White stone with blue veining and buff stone with reddish veining are varieties most common between Columbia and Sonora, Tuolumne County, in a marble belt about 25 miles long and up to 5 miles wide. Although large, sound blocks are obtainable, recent production has been confined to chips for terrazzo flooring. California marble has been used for interior building and for monuments, but there has been little activity in recent years. A large number of onyx marble deposits have been reported but most are too small for commercial development.

Colorado

Marble has been quarried extensively on Yule Creek near Marble in northern Gunnison County, about 10,000 feet above sea level. The marble occurs in massive beds at least 100 feet thick, with widely spaced joints that permit large, sound blocks to be quarried. Varieties quarried include those which are white, faintly clouded, and golden veined. A large mill was operated at Marble. Because of transportation difficulties, the deposit has not been worked for many years. This quarry had supplied marble for the Lincoln Memorial in Washington, D.C., and the superstructure of the Tomb of the Unknown Soldier in Arlington National Cemetery.

Colored onyx marble is produced in small quantities near Canon City in Fremont County for decorative uses. An attractive light buff travertine of excellent quality has been quarried near Salida in Chaffee County.

Florida

A porous stone described as travertine marble has been quarried near Bradenton and sold under the name "Floridene Stone."

Georgia

The principal marble areas of Georgia are confined to Pickens County in the north-central part of the State. The chief belts extend from Tate to a point beyond Marble Hill, a distance of 4½ miles. The valley of Long Swamp

Creek, one-half of a mile east of Tate, contains a bed of marble. On the west side are Creole, Cherokee, and Silver Gray quarries. The Etowah quarry is in the center of the bed. The silver-gray marbles are sold chiefly for monuments. Dark-clouded varieties from the Creole quarry are suitable for interior decoration and monumental use. The Light Cherokee quarry, which is very large and deep, furnished several shades of light- and dark-gray, coarsely crystalline, translucent marbles for both interior and exterior use. The nearby Mezzotint quarry supplied stone for interior decoration. Marble from the Etowah quarry is unusual. It has the coarsely crystalline structure of Georgia marbles but is characterized by green veinings and various delicate shades of pink, which have been attributed to the presence of finely divided particles of hematite. However, spectrographic analyses made at the University of Tennessee in 1956 showed no significant differences in the iron and manganese contents of the white, gray, and pink Georgia marbles.

Other important quarries are near Marble Hill, 3 to 4 miles east and northeast of Tate. Most of these workings are in a narrow, high-walled valley through which flows the east fork of Longswamp Creek. The marble is coarse-grained and translucent. Tremolite and phlogopite occur as accessory minerals in places. The Marble Hill quarries furnish white and clouded marbles. The Rosepia quarry supplied small blocks of a finer grained marble than that found in most Georgia deposits. The Amicolola quarry furnished blocks of unusually large size but the quarry is not in operation now.

The Georgia marble beds are 185 feet or more thick, and the reserves are extensive.

Light- and dark-green verde antique marbles in attractive patterns were produced near Holly Springs, Cherokee County. A black marble veined with white has been quarried at Ranger, Gordon County.

The light-colored Georgia marbles contain 93 to 99 percent calcium carbonate, have high strength and low absorption, and are used for exterior and interior building, memorials, and sculpture. A notable example of their use for sculpture is the heroic figure of Abraham Lincoln, carved by Daniel Chester French, in the Lincoln Memorial in Washington, D.C.

The bulk of the marble output is manufactured into finished products in large mills. Some is sold as rough blocks and slabs to independent mills throughout the country. Limited amounts of travertine have been produced near Cuthbert.

Maryland

White marble was quarried extensively years ago at Cockeysville, Baltimore County. Large quantities were sold for use in buildings. Lower grades were used extensively for residential doorsteps, a characteristic feature of Baltimore. Recently the area has produced crushed and ground products only.

A large serpentine area extends from the Susquehanna River near the Maryland-Pennsylvania border southwestward through Harford County into

Baltimore County. Extensive mining at Cardiff, Harford County, yields a dark-green, veined serpentine, a typical verde antique sold for interior construction and decoration. The chief output, however, is terrazzo chips.

The very beautiful maroon and gray "Potomac" breccia was once quarried near Point of Rocks, Frederick County, for use in early Washington, D.C., Government building interiors.

Massachusetts

White to gray dolomitic marbles were quarried some years ago near Lee, Berkshire County, and verde antique was mined near Springfield, Hampden County No dimension marble has been produced recently from either area.

Missouri

Marbles occur in widely scattered areas in Missouri. Chief production comes from Carthage, Jasper County. The marble is in heavy, coarsely crystalline beds of Burlington limestone (Lower Carboniferous age). It is white to light gray and uniform in texture and color. Although well crystallized, the marble shows little or no evidence of folding or distortion. Like Tennessee marble it has stylolites or suture joints that parallel the bedding and are 2 to 20 inches apart. Stylolites are common in marble used for interior construction but marbles for memorials and other exterior use contain only very fine stylolites. The marble takes a good polish and is used chiefly for interior work. A smaller quantity is used for exterior building and memorials. A mill is operated in conjunction with the quarry.

Marble quarried at Phenix, Greene County, belongs to the same geologic age and resembles the Carthage stone in many respects. Stylolites range in size from fine markings to wavelike zones that are 3 inches wide. In places the rock is fossiliferous. Sawed and cut marbles for interior use are the chief products.

Marble of the Kimswick Formation, which is much younger geologically than Burlington limestone, is quarried in eastern Ste. Genevieve County. Fossiliferous, golden-vein and rose types are well adapted to interior decoration. The walls of the elevator lobbies in the U.S. Department of Commerce Building, Washington, D.C., are good examples of such use.

Marble quarried in Jefferson County is used chiefly for terrazzo chips, roofing granules, and similar products.

Montana

Onyx marble occurs at Manhattan and Landusky in commercial quantity and quality. Travertine deposits up to 20 feet thick that exist near Gardiner have been worked since 1950.

Nevada

Dimension marble is produced from a quarry on the Elko-White Pine County line.

New Jersey

A light-green verde antique with attractive veining occurs near Phillipsburg, Warren County. It is quarried chiefly for terrazzo.

New Mexico

Onyx marble is produced west of Los Lunas, Valencia County, and also near Alamagordo, Otero County, and north of Las Cruces, Dona Ana County.

New York

Block marble was produced in New York years ago, notably at Plattsburg, Clinton County; Gouverneur, St. Lawrence County; and Wingdale, Dutchess County. Current activity in marble quarrying is confined to Westchester County, chiefly near Thornwood, where the stone is crushed to chips for terrazzo, stucco, cast stone, and roofing granules and is ground to a powder for whiting, asphalt filler, and other uses.

North Carolina

Commercial marble developments in North Carolina have been confined to a belt 1,600 feet to nearly one-half of a mile wide extending across Cherokee County. The earliest operations were near Murphy and Regal but close and irregular jointing in the marble beds discouraged quarrying in these areas. Recent production has been from the vicinity of Marble, where the joints are more regular and more widely spaced. Two types of marble are produced: A dark bluish gray, some of which is streaked and mottled with white and a more or less uniform gray. Some of the output is sold for exterior building use but most of the output is memorial stone.

Puerto Rico

Deposits of marble are found in many areas in Puerto Rico. A mottled white marble occurs extensively near Juana Diaz, northeast of Ponce, near the south coast; a black marble with white veins outcrops 3 miles north of Cidra; and a gray marble intersected by wavy bands of red outcrops on a cliff face near Rosario toward the western end of the island. All Puerto Rican marbles take an excellent polish.

South Dakota

A deposit of onyx marble has been reported near Custer in the Blackhills.

Tennessee

The marbles of east Tennessee occur in the Holston Member of the Chickamauga limestone of Ordovician age. The Holston beds of the Tennessee River Valley cropout in a series of nearly parallel northeast trending belts in an area about 20 miles wide and 125 miles long. Knoxville is near the center of the region.

Tennessee marbles range in color from gray through various shades of pink to red and black. They consist essentially of calcareous remains of two types of marine organisms--crinoids and bryozoa. The marbles are not greatly deformed; in many beds undistorted fossils are plentiful. Most of the beds, however, tilt at more or less steep angles. A characteristic feature of Tennessee marble is the presence of stylolites, locally called crowfoot. These irregular or zigzag markings occur in bands of one-tenth of an inch to 1 inch in width, generally parallel to the bedding and are a few inches to several feet apart. Tennessee marble has been used for steps, floor tile, and wainscoting in innumerable public buildings throughout the country. The marbles are notably pure, having a calcium carbonate content approaching or exceeding 99 percent. They also have low porosity. Tests at the National Bureau of Standards show an average of about 0.5 percent of pore space, and in some marbles the pore space is much less. Tests also show an average absorption of only 0.06 percent.

The bulk of the output in recent years has come from Blount, Knox, and Union Counties. The principal quarries of Blount County are near Friendsville The beds dip generally about 30 degrees but north of Friendsville they are nearly flat and crop out extensively. Most of the marbles are pink, but the so-called New Tennessee marble, produced in small quantities, is a light-gray, mottled dolomite of the Knox Group lying below the Holston marbles. Below the Knox dolomite dark beds in Grainger County yield black marble used entirely for interior decoration.

Marble is quarried extensively near Knoxville. Several companies operate quarries, and their mills produce a wide range of marble products. Colors range from gray to pink.

The largest Union County operations are near Luttrell. The marble bed in this area is about 75 feet thick and dips about 32 degrees. Colors range from light to dark red.

Tennessee marble is used chiefly for interior building but substantial quantities are used for exterior work. A notable example of exterior use is the National Gallery of Art in Washington, D.C. Smaller quantities are used for memorial stones and art work. Terrazzo and other crushed and ground products are made from quarry and mill waste. Other pieces of marble formerly wasted are trimmed and used for ashlar veneer.

Texas

The only marble-quarrying activity reported in Texas in recent years is production of terrazzo and roofing chats at Austin, Travis County.

Utah

Onyx marble has been quarried at Pelican Point on the west shore of Utah Lake, the Lake Mountains, the Cedar Mountains, and near Fillmore. White magnesian marble crops out on the west slope of the San Francisco Mountains in Beaver County. Other marble deposits are reported in Juab, Salt Lake, Sanpete, Summit, Tooele, and Utah Counties.

Vermont

The western marble belt of Rutland County is about 80 miles long and one-quarter of a mile to 4 miles wide. It lies chiefly between the Green Mountains and the parallel Taconic Range to the west. A parallel occurrence of marble known as the West Rutland Belt is about 6 miles long and one-half of a mile wide. Because of powerful crustal contraction and movement, the original horizontal limestone beds were crystallized into marble and, at the same time, folded into anticlines and synclines. During succeeding ages the crests of the folds eroded, leaving the marble exposed in long more or less steeply dipping belts. Records of drill cores and data from sections at the quarries show that the thickness of the marble ranges from 335 to 850 feet or more.

In most of the region a definite succession of workable beds may be traced. The entire succession is present in few, if any, localities. Each bed has its characteristic marble, which the quarrymen recognize and can trace from place to place.

The major joints generally are systematically arranged and are spaced so widely that large blocks can be obtained. Commercial marbles that abound throughout the belt are very pure; many contain 98 to more than 99 percent calcium carbonate. Their porosity is low, and their colors are white to cream, bluish gray, green, clouded, and mottled.

Following are the principal quarry locations, beginning at the southern end of the belt. A white to faintly cream, semitranslucent marble is obtained from extensive workings near Danby on Dorset Mountain. The amphitheater in Arlington National Cemetery was built of stone from this area. Similar marbles are quarried at Clarendon, Vt.

At West Rutland the marble structure is a truncated anticline, and the quarries fall in two groups--those on the western limb and those on the eastern. Several large quarry openings have been made on the western limb; these supply white and colored marbles, chiefly for interior use.

The eastern limb of the fold at West Rutland is the most productive marble area in Vermont. Quarries extending more than a mile along the strike of the fold include the well-known Covered quarry, an underground operation

400 feet deep and one-quarter of a mile long. The various beds in these quarries furnish white, bluish, greenish, and pink architectural marbles.

Bluish-white marbles mottled with gray are quarried near Proctor, Pittsford, and Florence. The Pittsford Valley quarries are noted for the large, sound blocks obtainable. A typical stone quarried at Brandon toward the northern end of the belt is a light-bluish gray marble having a mottled appearance because of the recurrence of fine, gray, plicated beds.

Marbles occur in certain areas in Vermont outside of the western belt. Reddish, or mottled red and white, siliceous so-called Champlain marbles are quarried near Swanton, Franklin County. Because of their high resistance to abrasion, they are particularly well adapted for floor tile and stair treads.

Marble, with an almost black polished surface but interspersed with characteristic white circular fossil casts, occurs on Isle La Motte in Lake Champlain, Grand Isle County. Verde antique marbles are obtained at Roxbury, Washington County, and Rochester, Windsor County. Large sawing and finishing mills are operated at West Rutland, Center Rutland, Florence, Proctor, and elsewhere. Vermont marble is used for exterior and interior building and decoration, for monuments, sculpture, and miscellaneous purposes.

Virginia

A serpentine marble that is black when polished is quarried near Harrisonburg, Rockingham County. Recent production consists chiefly of terrazzo chips.

Washington

Marbles in a variety of colors, including red, pink, white, and black, are quarried near Chewelah, Stevens County. The output consists at present of terrazzo chips and similar products.

Wyoming

White marble is quarried near Wheatland and green serpentine marble near Glenrock.

Granite

In 1966, 21 States reported dimension granite production to the Bureau of Mines. Production was concentrated in the crystalline rock provinces of the east, far west, and Lake Superior regions. Scattered production was reported from a few States in the central predominantly sedimentary province, notably Missouri, Oklahoma, and Texas (fig. 9).

California

Granitic rock underlies 40 percent of California and represents 75 percent of the total dimension stone that has been produced.

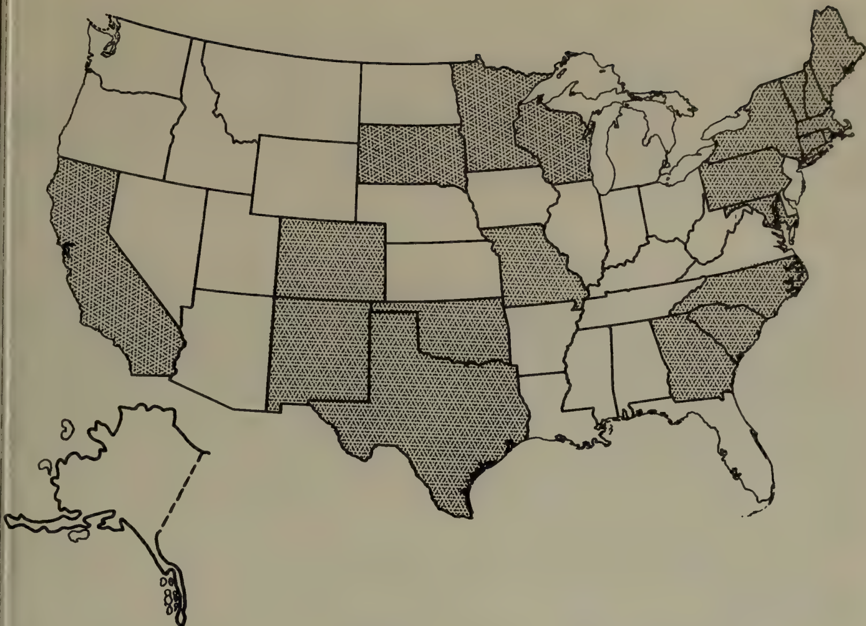

FIGURE 9. - States Producing Dimension Granite in 1966.

A light-gray granite specked with black mica crystals quarried at Raymond, Madera County, has been used extensively for architectural work. Building granites are produced also near Rocklin, Placer County. Gray granite for monuments and surface plates are quarried near Lakeside, Vista, and Escondido, San Diego County.

Colorado

Granite is or has recently been produced from Larimer, Chaffee, and Fremont Counties. Earlier production had been reported from Clear Creek, Gunnison, and Teller Counties.

Connecticut

The granite industry of Connecticut formerly was centered chiefly in southern New London County. Today, buff, light-gray, and dark-gray granites are quarried for structural and ornamental uses near Stoney Creek, New Haven County; Glastonbury, Hartford County; and Oneco, Windham County.

Georgia

A fine-grained, gray granite gneiss is quarried at Lithonia, DeKalb County, for building stone, paving blocks, and curbing. Elberton, Elbert County, is the center of a memorial-stone industry that produces large quantities of monumental granite. A medium-grained light-gray, a fine-grained dark, and brownish-pink granite are produced. More than 20 quarries and finishing mills usually operate in this area.

Maine

Granites are widespread in Maine. In 1930 two-thirds of the output of block granite consisted of paving stones and curbing. Maine produced more than 40 percent of all the granite paving blocks made in the United States but this branch of the industry has almost vanished. The principal products currently marketed are building and memorial stones and curbing. The largest quarries are in deposits of medium- to coarse-grained gray biotite granite near Stonington and Mt. Desert, Hancock County. Fine-grained granites are quarried at Frankfort, Waldo County, and St. George, Knox County, and near Wells and York, York County. A light-gray almost white architectural granite was once quarried at North Jay, southern Franklin County.

Maryland

Architectural granite is produced near Port Deposit, Cecil County.

Massachusetts

One of the leading centers of building-granite production in the United States is the West Chelmsford, Graniteville district, in Middlesex County. The rock is a uniform gray granite that has a wide market range. Pink granite is quarried at Milford and light-gray granite has been quarried at Uxbridge, both in Worcester County. A granite ranging from greenish gray to dark bluish gray is quarried near Quincy and Weymouth, Norfolk County, and Hingham, Plymouth County. Quincy was at one time an important center of memorial-stone production but the recent output has been relatively small. Green granite is quarried from time to time near Rockport and Gloucester, Essex County.

Minnesota

Most granites produced in Minnesota are used for architectural purposes. They are quarried chiefly in the St. Cloud area in Stearns County and in the Minnesota River Valley. Medium- to coarse-grained red granites are those used most widely for monumental stone. A coarse-grained, pinkish-gray, architectural granite is produced near Cold Spring and Rockville, Stearns County. A biotite-granite gneiss with distinct banding, quarried near Morton, Renville County, is used widely for base courses of large buildings. Pink and red granites, used to some extent for architecture but chiefly for memorials, are quarried near Ortonville, Big Stone County, and in Mille Lacs and Stearns Counties.

Missouri

A dark-red granite provides attractive dimension stone from Graniteville, Iron County.

Montana

Granite for monument stone is quarried intermittently from three quarries within a 5-mile radius in Jefferson County and near Gardiner, Park County.

New Hampshire

A fine-grained gray granite quarried near Concord, Merrimack County, is used extensively for building purposes. A fine-grained, blue-gray granite occurring near Milford, Hillsboro County, is applied chiefly to memorial uses. Both building and memorial granites are produced near Redstone and Conway, Carroll County. Two types are available--one pinkish-gray and the other yellowish-green.

New Mexico

Monumental and ornamental granite is produced northeast of Las Vegas in San Miguel County.

New York

In 1965, dimension granite was produced near Yonkers and White Plains, Westchester County, and at Jay, Essex County.

North Carolina

The most productive structural granite area in North Carolina is near Mount Airy, Surry County. The rock is a light-gray, almost white, biotite granite of medium texture and is used extensively for bridges and buildings. A pink granite quarried near Salisbury, Rowan County, is applied to both building and memorial uses.

Oklahoma

Memorial stones are quarried at Granite, Greer County, and Snyder, Kiowa County. The rocks of the former area are medium-grained red and pink. The prevailing type at Snyder is a fine- to medium-grained stone mottled pink and gray.

Pennsylvania

The granite gneisses of the Philadelphia district have been used extensively for house veneer.

Rhode Island

A fine-grained pinkish or buff and bluish-gray biotite granite is quarried near Westerly, Washington County, chiefly for memorials.

South Carolina

A fine-grained gray biotite granite is produced near Rion, Fairfield County.

South Dakota

South Dakota has become one of the leading producers of memorial granite. The rock occurs in a belt that extends from Big Stone and Renville Counties, Minn., into Grant County, S. Dak. Quarries near Milbank and Bigstone City furnish granite characterized by a dark to medium red color. Depth of quarrying has exceeded 200 feet.

Texas

A coarse-grained, red granite quarried near Marble Falls, Burnet County, is used as architectural stone and also for jetties and breakwaters. A fine- to medium-grained gray granite quarried near Llano is used almost exclusively for memorials. Precambrian granite is quarried in El Paso County on the east flank of Franklin Mountains and used as masonry stone (rough building stone). In Gillespie County, Precambrian granite is quarried at Bear Mountain, about 4 miles north of Fredericksburg for use as building stone (rubble and rough architectural stone).

Utah

Commercial granite has been produced from Willard, Box Elder County; Little Cottonwood Canyon, Salt Lake County; Alpine, Utah County; Heber, Wasatch County; and Ogden, Weber County.

Vermont

A fine- to medium-grained gray to white biotite granite of uniform texture is quarried extensively near Barre, Washington County, for memorial uses (fig. 10). Much of it is fashioned into finished monuments in numerous mills in the Barre area. The stone has a wide market range. Granite occurs in many other places in Vermont, and in past years was quarried extensively for building and memorial uses in Caledonia County (Ryegate granite), Windham County (Dummerston White), Windsor County (Bethel White), and various other localities.

Virginia

A bluish granite has been produced near Burksville, Nottoway County.

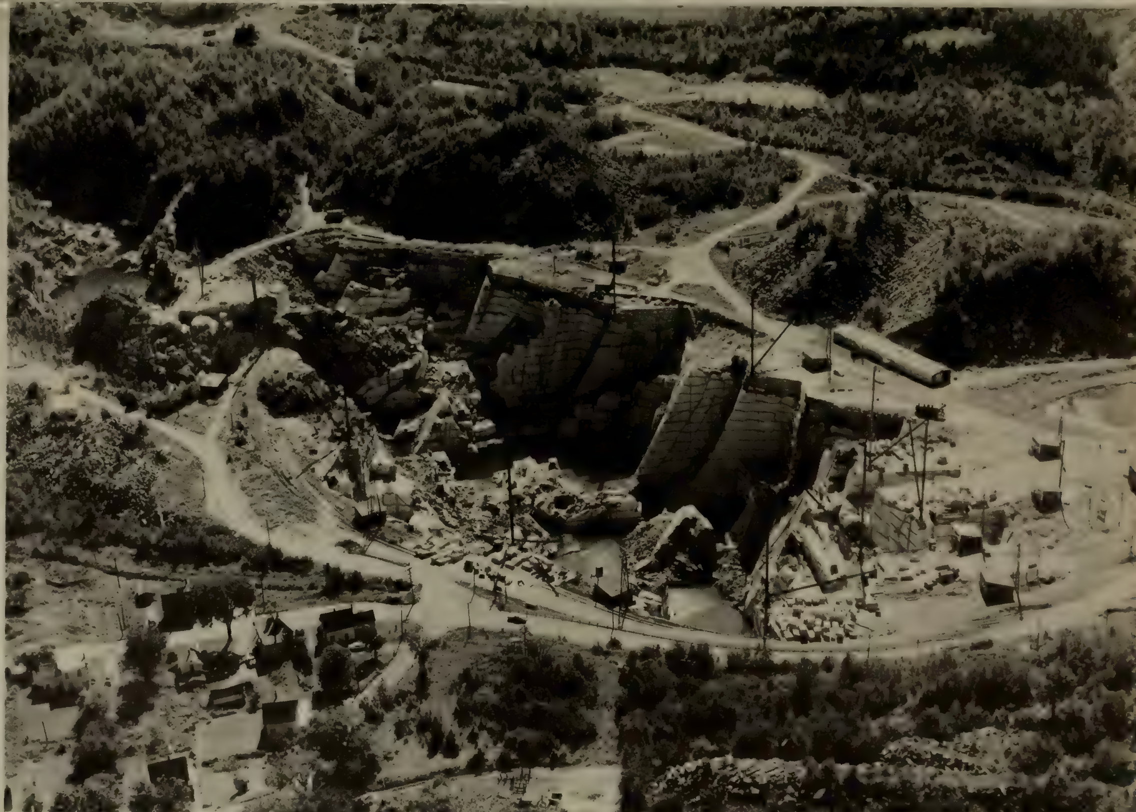

FIGURE 10. - Vermont Granite Quarry. *(Courtesy, Rock of Ages Corp.)*

Wisconsin

The reddish-brown to brilliant red granites of the Wausau district, Marathon County, the coarse-grained red to pale pink stones occurring near Amberg, Marinetta County, and the fine-grained, grayish-red to bright-red granites produced at Montello, Marquette County, are used chiefly for memorial stones, although they are used architecturally at times.

Granite is produced near Mellen in Ashland County and near Lohrville in Waushara County primarily for building purposes. Dimension granite produced in Wisconsin has one of the highest average values of any granite produced in the Nation. Wisconsin granite generally contains from 66 to 77 percent silica 10 to 21 percent alumina, 2 to 10 percent potash, and 2 to 4 percent sodium. Wisconsin granite is of the Precambrian age.

Traprock

In 1966 five States reported production of dimension traprock to the Bureau of Mines. In order of tonnage produced, the five States were Washington, Virginia, Pennsylvania, New Mexico, and Oregon (fig. 11).

California

A gabbro consisting essentially of plagioclase feldspar, hornblende, and mica, with little or no quartz, is quarried mainly from deposits west and south of Escondido, near Lakeside, and east of Vista in San Diego County. As a typical black granite, it takes a brilliant polish with a black surface. Stone is produced partly from shelf quarries in the massive rock and partly from boulders that occur at the top of the outcrop. The principal products are architectural stone and surface plates but memorial stone is also produced

Gabbro is quarried 2 miles east of Loomis, Placer County. It is cut and polished at Rocklin and sold chiefly for monuments but also for building stone and fireplace stone.

A dark hornblende diorite is quarried 1 mile northeast of Academy in Fresno County. Blocks of very large size may be quarried if desired. The stone is cut and polished in Clovis for monumental or architectural use.

Dimension basalt was formerly produced in Marin, Napa, Solano, and Sonoma Counties.

Connecticut

Basalts and diabases that occur in the central Connecticut lowland were formerly a source of dimension stone.

Idaho

Traprock occurs widely in northern Idaho and quarries occasionally produce rubble as a byproduct of crushed stone operations.

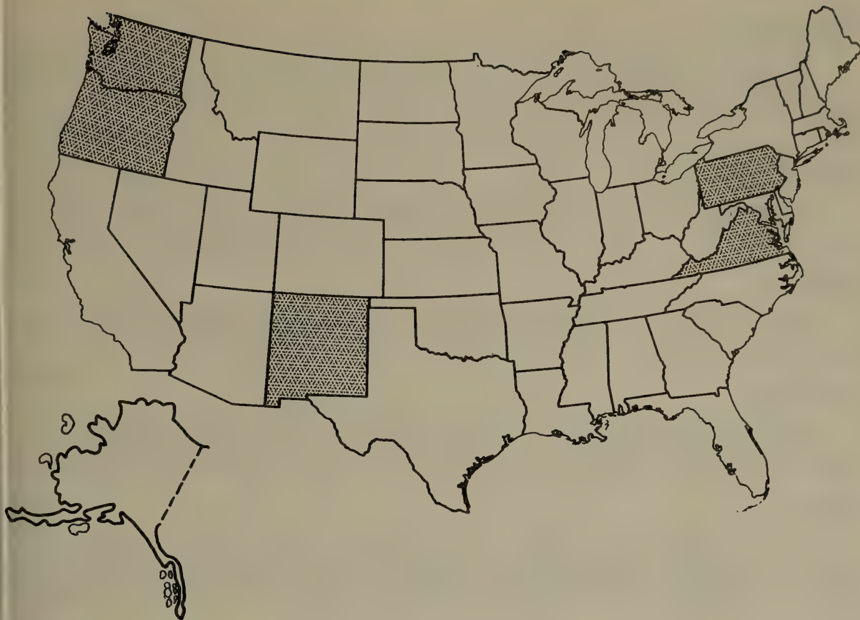

FIGURE 11. - States Producing Dimension Traprock in 1966.

Maine

An olivine norite that takes a brilliant polish was quarried many years ago at Lincoln, Waldo County, and conveyed 7 miles to Belfast for dressing into monuments.

An almost black hypersthene-olivine gabbro was quarried for many years near Addison but there has been no recent production. The stone polished well and was used for monuments and for architectural work. A norite occurring at Baileyville, 7 miles southwest of Calais, and a quartz diorite at Calais were quarried many years ago.

A gabbro that polished with a dark-olive surface has been quarried for memorial use at Berwick. Black amphibolite crops out at several points in Oxford County, including Plumbago Mountain.

Maryland

Baltimore, Cecil, Harford, and Howard Counties contain important traprock resources.

Massachusetts

Basalts and diabases are widely used sources of crushed stone with past production of minor amounts of dimension stone. The Boston metropolitan area and the Connecicut Valley are the principal sources.

Michigan

Rubble is produced as a byproduct of crushed stone in Michigan. Quarry centers are in Marquette, Gogebic, Houghton, and Iron Counties.

New Jersey

Diabase intrusives are widely developed from the palisades of the Hudson River westward through the northern counties to the Delaware River.

New Mexico

Deposits of dark lavas and scoria are widely distributed in New Mexico. Small quantities are produced, from time to time, for dimension stone use.

New York

The palisade diabase sill extends from near Haverstraw to the vicinity of Richmond on Staten Island. The sill is 300 to 800 feet thick and still a source of crushed stone, although no longer a source of dimensioned blocks.

Oregon

Both rough construction blocks and rubble are byproducts of crushed trap rock in this State. Raw materials crop out in many counties although the northwestern and southwestern counties constitute the principal sources along with Wallowa County in the extreme northeast.

Pennsylvania

A diabase intrusive completely surrounds Quakertown and extends from it for 1 to 4 miles. The rock consists essentially of lathlike crystals of feldspar with augite filling the spaces between them. It possesses an unusually high compressive strength, has a uniform texture, and takes a brilliant polish.

A quarry operation for dimension stone is located 2 miles east of Coopersburg. The excavation is large because the rock has been quarried for many years. Joints are spaced widely enough to permit the removal of large, sound blocks suitable for building stone, memorials, or other products. Most of the stone quarried has a moderately fine granitic texture, but some of it is very fine grained. This type presents a velvet black polished surface. The quarries are in Bucks County, but the company operates a well-equipped stone finishing mill at Coopersburg in Lehigh County. The principal products are precision surface plates described in a preceding section on uses. Memorial and structural stones are also produced. Coopersburg granite is well

adapted for carved ornamental and architectural designs. Quarries have been worked in earlier years in other parts of the diabase deposit, notably at Quakertown and nearby points.

Diabase similar to that in Bucks County occurs in two areas in the northern part of Chester County; the one at St. Peters has been quarried. The rock is massive and of uniform texture, and the joints are favorably spaced. The quarry is more than 150 feet deep. The diabase is well adapted for memorial and architectural uses and particularly for making surface plates. Nearby Philadelphia affords a convenient market for architectural stone products. The stone is fabricated in a well-equipped mill.

Traprock for rough construction is quarried at Montgomeryville in Montgomery County, and similar rock is quarried in Delaware and Berks.

Virginia

Traprock occurs in Albemarle and Fauquier Counties, near Leesburg (Loudoun County), and at Bull Run on the boundary between Fairfax and Prince William Counties.

Washington

Traprocks are distributed extensively in Washington except in the northwestern area. Quarries have been located in more than 20 widely scattered counties.

Wisconsin

A dark gabbro occurring near Mellen has been quarried from time to time for many years. Traprock also crops out in Marinette and Polk Counties, with some dimension stone production reported from the former county.

Slate

The major slate-producing districts of the United States are the Monson district, Maine; the New York-Vermont district, including Washington County, N.Y., and Rutland County, Vt.; the Lehigh district, including Lehigh and Northampton Counties, Pa., and Sussex County, N.J.; the Peach Bottom district including Lancaster and York Counties, Pa., and Harford County, Md.; and the Buckingham County and Albermarle County district of Virginia. These districts produce one or more of the principal dimension slate products, namely roofing slate, millstock, or flagging. Irregular production is also reported from other States including Arkansas, California, Georgia, Michigan, Tennessee, and Utah (fig. 12).

Maine

Slate occurs in Maine in a belt 15 to 20 miles wide lying at about the center of the State in southern Piscataquis County. The strike is in general northeast, and the dip is very steep, ranging from 80 degrees to vertical.

FIGURE 12. - States Producing Dimension Slate in 1966.

Production is confined almost exclusively to the vicinity of Monson. The com- mercial beds consist of fine-grained, dense, uniform, blue-black slate. The slaty cleavage is vertical and therefore is nearby parallel with the bedding. Underground mining is conducted chiefly on one 9-foot, nearly vertical bed and on several adjacent smaller beds. Monson slate is especially adaptable for making switchboards, panels, and other electrical insulators. Production has been recorded at times from nearby North Blanchard and Brownsville.

New York-Vermont

An important slate district extends from Rutland County, west central Vermont, into Washington County, N.Y. The slates are of two geologic ages; those of Ordovician age including red, bright green, and black slates and those of Cambrian age including green, purple, and variegated slates. In general the slaty cleavage dips east 30 to 50 degrees and either parallels the beds or crosses them at a low angle. This area is the source of the so-called colored slates. One type is the sea-green slate. When this slate is first quarried, it is gray or slightly greenish gray and after a few years of exposure, its color changes to a buff or brownish gray. This color aging is preferred by some architects and builders. Another type is the unfading green.

This slate maintains its greenish-gray color indefinitely. The so-called purple slate is a purplish brown, the purple color being attributed to a mixture of the red of hematite with the bluish green of chlorite. A variegated type is greenish brown with irregular purple patches giving a mottled effect. Red slates associated with bright-green varieties of Ordovician age occur near Granville, Washington County, N.Y. The red color is due to abundant hematite. These slates are used at times for roofing.

Aside from crushed and ground slate, the products of the Washington County, N.Y., quarries centered near Granville and Middle Granville are roofing slate, flagging, and millstock. In the southern slate district of Vermont, which extends from Poultney to West Pawlet, the chief products are roofing slate, flagging, and millstock. In the northern district of Vermont near Fair Haven, both roofing and flagging are produced. Certain purple and green slates are used for making products such as floor tile, vats, mantles, baseboards, sills, steps, and to a small extent billiard-table tops and electrical panels.

Heavy "architectural" slates from the New York-Vermont area are sold widely for ornamental roofs. When used on large buildings with proper color blending and gradation in size, they produce effects rarely equaled by any other roofing material.

Pennsylvania-Maryland

Slates of Lehigh and Northampton Counties occur in a belt 2 to 4 miles wide on the south side of Blue Moutain extending from the Delaware Water Gap southwest to a point 4 miles west of Lehigh Gap--a distance of about 32 miles. Quarries centered near Bangor, Pen Argyl, Windgap, and Slatington constitute the most productive slate area in the United States. The Sussex County, N.J., area has produced a small quantity of slate.

Slate occurs in the Martinsburg Formation of Ordovician age. It overlies the Jacksonburg limestone, and to the northwest it dips beneath the Silurian conglomerate and sandstone of Blue Mountain. The slate belt is 1,600 to 600 feet wide but only a few hundred feet are of commercial quality. The slates are of two types. The lower hard-vein belt occurs farthest south, passing through Belfast and Chapman quarries. Above it are beds of sandstone and higher still is the soft-vein slate belt, which extends from East Bangor through Bangor, Pen Argyl, Windgap, Danielsville, and Slatington to Slatedale.

The original bedding of the rock is marked by dark bands known as ribbons, which have been already described. The ribbon-free "big beds" are particularly prized. The soft-vein slate is used for roofing and also for the full range of millstock products. This area produces a large percentage of all the millstock products made on the North American Continent. Almost all of the slate blackboards marketed come from this belt. School slates are produced chiefly in the Slatington area. The hard-vein slate is used almost exclusively for roofing and flagging.

The slate of the Peach Bottom district extends over the State line into Harford County, Md. It is regarded as of Precambrian age and overlies older gneisses and serpentine. The slate occurs in three parallel belts 75 to 120 feet thick. Slaty cleavage is vertical of dips at a steep angle. Many years ago an important roofing-slate industry flourished near Delta, Pa. The dark, bluish-gray slate with a lustrous cleavage surface had a high reputation but there has been no recent production. Granules and flour are the only slate products now made in this region.

Virginia

The best commercial slates of Virginia occur near Arvonia, Buckingham County, in a belt 200 to 250 feet wide and about 1 mile long. The rock has been identified as of Ordovician age. The bedding dips at steep angles of 80 to 85 degrees, and the slaty cleavage parallels the bedding. The slate is dark gray or slightly greenish with a lustrous surface. It is too hard for use in millstock products. Some flagging is produced but the main product is facing or roofing slate. Several quarries have been operated in the area for many years.

Miscellaneous Stones

Stones of various other types are often used for dimension purposes. In 1966, 11 States reported production of miscellaneous dimension stone varieties (fig. 13). The most common stones so classified include greenstones, various schists and phyllites, volcanic tuffs and lavas, pumice, scoria, mylonite, tripoli, diatomite, mariposite, and wollastonite.

A well-known greenstone consisting essentially of actinolite and chlorite is quarried near Lynchburg, Va. It is used as structural and ornamental building stone and its nonskid qualities recommended it for floor tile and steps.

Schists of many types are used particularly for ornamental purposes in buildings and fireplaces. Unusual effects are achieved by using schists in combination with other stones. A Connecticut garnet schist, which is quarried from time to time, is typical of such stone. Tuffs and lavas of many types are quarried, particularly in the western continental States and Hawaii and are sold under various trade names. Unusual textures or color shades and variations lend them value to achieve special architectural effect. Most commonly the stone is laid up rough rather than cut or sawn to achieve "rustic" or "western frontier modern charm."

Tuffs were a popular building stone in the early west because the less well-indurated varieties could be shaped with a crosscut saw. Soapstone, particularly from Virginia, has also had a long history of specialized use in laboratory sinks, tables, tanks, and by industries handling caustic or otherwise aggressive chemical solutions. Production of dimension soapstone has been recorded from Virginia, Maryland, North Carolina, Rhode Island, Vermont, California, and Washington. The principal locality, however, is near Schuyler, Nelson County, Va., where irregular lenticular bodies are exploited.

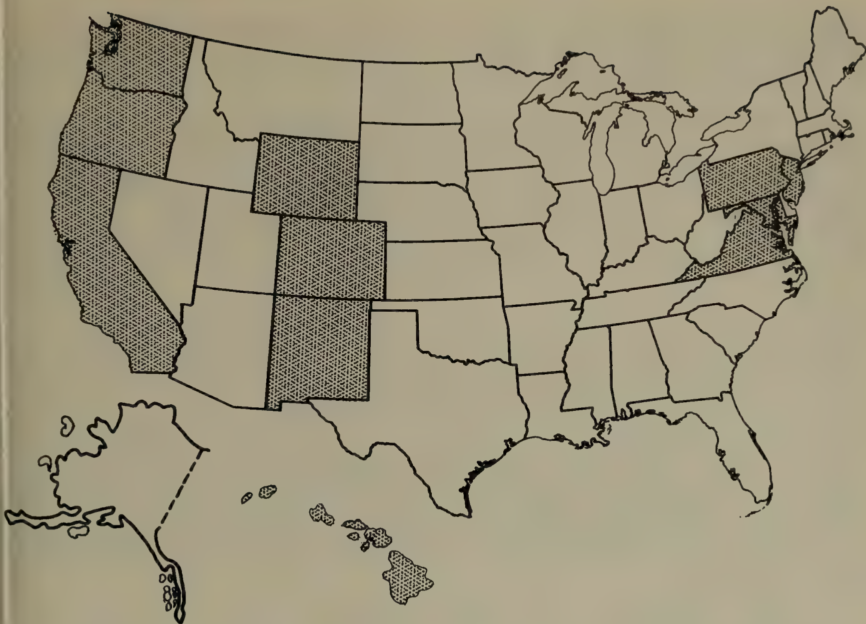

FIGURE 13. - States Producing Dimension Miscellaneous Stone in 1966.

Fieldstones and boulders of all types are used in all parts of the country for fireplaces, chimneys, fences, and even homes or clubhouses. Mine or quarry dumps are also culled for unusual rock, particularly in pegmatite mining districts where oddities such as chimneys of feldspar-mica-quartz pegmatite and beryl crystal gateposts or graveyard markers may bring new adventures in aesthetics to the discerning observer. Stones stained blue or green by copper carbonates and silicates are recovered from western copper-mining districts. Even petrified wood has had recent popularity for such use as fireplace facing.

Foreign Resources

Many foreign countries are blessed with an abundance of beautiful and enduring structural and ornamental stones (10). Because of long centuries of use, some of the quarries that were the sources of classic stones, such as some Mediterranean marbles, have been depleted. However, other quarries have taken their place. Many of the foreign stones have endured the test of time for many centuries and their use in centuries-old cathedrals and other edifices, which still stand, offer testimony to their excellence. To prepare a treatice on all foreign stone resources would not be possible here. Those

foreign stones finding use from time to time in the United States or those that compete in markets with domestic stones or have special historical interest will be given primary attention.

Certain types of stone are naturally associated with certain areas on the earth's crust. About one-third of the earth's dry land surface is underlain by basement complex crystalline rocks forming the so-called "shield" areas or continental cores. Such regions include most of eastern Canada, parts of Brazil, India, Australia, Siberia, and Africa and "Fennoscandia" (northern Scandinavia, Finland, and extreme Northwestern U.S.S.R.). As one might expect the basic building stones utilized here are the igneous rocks such as granite and gabbro, with lesser amounts of marble. Over the other two-thirds of the continents, the basement rocks are concealed beneath greater or lesser thicknesses of sedimentary rocks with belts of metamorphic and igneous rocks included where orogeny has disturbed the crust. Limestone and sandstone are the common widespread building stones in the sedimentary areas, with marble, slate, and granite prominent in the metamorphic belts.

Canada, Scandinavia, and Scotland as one would expect have been prominent users of granite. Northern France, Belgium, and England have well-developed limestone and sandstone resources. The long Mediterranean east-west orogenic belt has been a prominent source of marble over its entire length--Portugal, Spain, North Africa, France, Switzerland, Italy, Greece, and India are just a few of the countries that have made fruitful use of the variegated indigenous marbles available.

Industry ranges from rudimentary hand labor in less developed lands to highly organized quarrying and marketing facilities in Europe. Following the same trends as in the United States, fewer massive blocks are used today, with thinner panels and cut stone brick and ashlar replacing such massive construction practice in many lands. Dimension stone use, in general, has declined because of the use of concrete and other construction materials that require less labor.

Canada

Because of its long common border with the United States, many Canadian building stones have been marketed in this country from time to time. The building stones of Canada have been described in great detail in a series of publications by the Canada Department of Mines and Technical Surveys, formerly Department of Mines and Resources (50, 82). Marble, granite, and sandstone are all shipped from Canada to the United States at present.

Granite of many colors and textures are abundant in Canada. This is because much of the Nation is underlain by the great Archean "Canadian shield" that consists mostly of very ancient granites and gneiss. In particular, black granite from Quebec has had recent popularity in the United States but reds, greens, grays, and pinks from many Provinces are quarried or have had periods of popularity. Canada, particularly Quebec and British Columbia, is similarly blessed with many types of marble which have been exploited relatively little. These varieties include serpentine (verde antiques), rose

breccias, cream-banded marble, and others. Only Quebec reports marble production at present. Limestones have been a popular building stone within Canada. The mottled buff and gray Tyndall (Ordovician) limestone has been used in Winnipeg and other Midwestern Canadian cities. In Ontario the dark to light gray limestones of the Trenton and Niagara Groups and the Black River and Onondoga Formations have been widely used. In Quebec Province the semicrystalline gray Chazy and Trenton limestones have been most popular. Sandstones of various colors have been quarried at several points but the white, brown, and yellow Cambrian sandstones of southern Ontario have been the most important. In eastern Quebec some slate is produced. Black is the most common color although some green- and red-colored slates also occur.

Mexico

Mexico is a convenient and major source of onyx marble for the United States market. Formerly marble was quarried mostly in Baja,California, the principal sources are now near Puebla and Tehuacan in Puebla and near Salina Cruz in Oaxaca. Mexican stone is of excellent quality and beauty; it is noted for its translucency, freedom from flaws, and fine banding. Colors are delicate with light green, pearl white, light rose, and pale brown tones prevailing. All are more or less variegated by fine veins of rose, pale brown, or yellow. One popular trade name for such onyx marble at present is "Tecali onyx." Resources are, for all practical purposes, inexhaustible. Blocks up to 3 by 3 by 2 feet are readily available from surface quarries. Larger blocks and plates are obtainable on special order.

Belgium-Luxembourg

A blue-gray to black Devonian limestone has been widely quarried in Belgium. Because it consists largely of crinoid stem fragments, it has a polished texture somewhat resembling a granite at first glance. A local term for the stone is "petit granit."

Small deposits of marble, including fossiliferous varieties, have been worked at several places. The most famous has been "Noir Belge" quarried near Namur and considered by some to be the world's finest black marble.

Slate production has centered on Neufchâteau and on the Belgium-Luxembourg border near Martelange.

Eire

Several very attractive marbles have enjoyed periods of popularity. Among these are "Irish Black" from Galway (black studded with white shells), "Kilkenny Black," "Galway (also called Connemara) Green" (a verde antique type), and a red marble from near Shantallow. Expansion of Galway harbor facilities and building of a new marble manufacturing plant in 1965 helped to stimulate export of many of these famous marbles.

Red and gray granites have been worked at many localities, and green and blue-gray slates occur in Kerry and Tipperary.

France

France lies athwart the great Mediteranean marble belt and is blessed with a diversity of other dimension stones as well. Marbles of all colors, color combinations, patterns, and types occur. The exploitation of some date back to the days of the Roman occupation. Some of the more famous French marbles include "Sarancolin," a banded and mottled multicolored breccia from Hautes-Pyrénées, "Fleuri" type marbles with flowerlike markings from Calais, "Saint-Beal," a pure white statuary marble from Haute-Garonne, "Le Grand Noir, a black marble from Doubs, "Le Grand Diable" from Aude and "Le Petit Diable" from Aubert, both of which are mixed black and white, "Stalactite du Bédat," an onyx marble from the slope of the Pyrénées, and so many other fine marbles including reds, fossiliferous, and "Cipolin" types.

Limestones have also been widely utilized. "Caen stone," a light-colored Jurassic oölite type has been used throughout Europe and some even in the United States. Similar stone in Meuse and Yonne has been popular in Paris. Within the Paris area the "Calcarie Grossier," a Tertiary yellowish to grayish white stone, has even been quarried beneath parts of the city itself. In Southern France, Tertiary limestones have been widely quarried. Sandstone has been worked for local use in many parts of the Nation. Granites are widely distributed; the most popular for dimension use have been grays from Calvados and Manche and several colors from Finisterre. Slate of various shades has been quarried, mostly underground, from six districts: Angers, Finisterre, Ardennes, Correze, Pyrénées, and Savoie.

Greece

The "glory that was Greece" was mostly preserved in marble. Greek architecture and statuary were the first to fully explore the potential of the stone. The skillful use of marble is a direct result of its abundance both on the mainland and the Greek islands. The most widely used have been "Parian," a subtranslucent white from Paros similar to Carrara; "Pentelic," used in the Parthenon from Mount Pentelicus near Athens; "Rosso Antico," a red; "Nero," a black; and Cipollino," a white and pale-green, so-called because of its supposed resemblance to a cut onion. "Vert Antique," a green serpentine from Thessaly, is probably the original "Verde Antique." "Vert Tinos" from the Island of Tenos is a light-green stone with white veins.

Italy

Like ancient Greece, the splendor of Rome was based on marble. The principal Roman structural marble was actually a travertine from the world-famous quarries at Tivoli, 16 miles east of Rome. The Colosseum and St. Peters are among the classics made of Tivoli travertine and in copy of the sumptuousness of the Romans, the now demolished Pennsylvania Station in New York City was made from it. Many of the ancient Roman terms for classic marble varieties are still used today. A pure white marble is often called "Carrara" despite its source; "Sienna" means not only a certain colored marble but is a general color term as well; other terms like Fleuri, veine, and verde are also in common use. The famous Italian marbles are too many to name here but are

discussed in "I Marmi Italiani" (31). A few of the more noteworthy are "Carrara," the fine-grained translucent white marble already mentioned and first worked about 283 B.C.; "Pavonazzo," cream with green and yellow markings; "Cipolin," white with greenish markings; "Arabescato," white with a network of complex veins; "Calacata," white with yellow streaks; "Bardiglio," pale dove with dark veins; "Breche de Seravezza," a breccia; "Pietrà di Volegma," greenish white; "Rosso Antico," deep red; "Viola Antico," purple; "Brocatello de Siena," yellow with purple and black veins; "Paonazzo de Siena," yellow with predominant purple veins; "Gray Sienna," gray with yellow veins; "Sienna Unia," bright yellow; and "Verde di Genova," green, brown, and red serpentine fragments cemented with white or greenish calcite. In addition to the Carrara, Siena, and Genoa areas many other marbles have been produced from Verona, Vicenza, Liguria, and other areas.

The most famous Italian granite is red granite from the west bank of Lake Maggiore about 100 km from Milan. The province of Genova is a source of slate for roofing, blackboards, billiard tables, and electrical use.

Norway

Norway is noted for its world-famous Laurvikite, a gray syenite with an interesting display of colors and known to the trade as "Norwegian Pearl Gray." Nordmarkite is a red microperthite syenite quarried north of Christiana. White, pink, and green marble occurs at Dunderland, 150 miles north of Trondhjem. Slate near Bergen is useful for decorative structural applications and flagging. It is unique in that small knots of silica give it the appearance of bird's-eye maple.

Portugal

Also athwart the Mediterranean marble belt, Portugal is a choice marble source. Villa Vicose and Cintra Centra are the primary source areas. The most famous stones have included "Lioz Bianco" (white); "Lioz Creme" (buff-cream); "Lioz Rosa" (rose); "Rose Aurore" (rose and cream); and "Janne de Portugal" (yellow). Dark blue-gray slate has been worked at Vallong, 11 miles northeast of Oporto.

Spain

Many attractive Alpine marbles are found in Spain including micaceous roses, blacks, reds, cipolinos, fossiliferous, and onyx. The provinces of Badajoz and Guipuzcoa are noted for slate.

Sweden

The Swedish "black granite" is actually a gabbro from the Province of Jonkoping. "Swedish Rose" a red granite is also popular. "Swedish Green" is a marble from Norrkoping. The best slate in the country is at Kellsvik near Lake Wena.

United Kingdom

Limestones have been the key structural stone in England. "Bath stone," a Jurassic oölite, has been the most famous. It has been used for many ecclesiastical structures in Western England. "Portland stone," the favorite stone of Architect Sir Christopher Wren, occurs on Portland Isle off the Dorset coast. Its most famous expression is St. Paul's Cathedral, London. In both England and Scotland extensive use has been made of both the Devonian "Old Red Sandstone" and the Triassic "New Red Sandstone." The latter is equivalent to the "brownstone" of the United States. Scotland has been long noted for granite from its rock-ribbed hills. From Aberdeen fine- to medium-grained gray granites have had long international fame. Red granite from Peterhead polishes well and, in fact, was the first standard granite memorial stone in the United States. Several English granites have also been quarried, perhaps the most famous being gray porphyritic stone from Devon used in the 1756 construction of the Eddystone light. Brown marble has been mined in Wales and black marble on the Isle of Man. Several types of marble of various colors have been quarried in Devon and Derbyshire. "Cornish serpentine" is a dark olive-green verde antique from Cornwall. The most famous slate industry in the world has been the Welsh one. Slate was worked as early as the Roman occupation, and it has been an important industry since the late 18th century. The five most important Welsh areas have been Carnarvon, Blaenan Festiniog, Prescelly, between Towyn and Corris, and between Llangollen and Corwen. Several other slate producing districts are in England and Scotland.

North Africa

North Africa is on the southern edge of the Alpine-Mediterranean marble belt. Ancient Rome and Carthage made wide use of so-called Numidian marble from Algeria, Morocco, and Tunis. These included a pure white statuary, a black (blue Turquin), a yellow arborescent (the original prized "Numidian"), yellow with a reddish tint ("Giallo Antico"), and various pinks, reds, and cipolins. Algerian onyx marble has been used as far away as in Parisian church windows in place of stained glass. "Egyptian alabaster" is an onyx marble from the Nile Valley. An Egyptian reddish hornblende granite from Syene near Aswan was quarried as early as 1300 B.C. Although not a true syenite, it gave its name to such quartz deficient granitic rock.

Other Countries

Needless to say, many nations are justly proud of their native stones. Ancient civilizations the world over made aesthetic and well-engineered structures from the rocks at hand. As many of these nations renew their economies, more and more of these stones will reenter commerce. Latin America, Africa, and Asia contribute many beautiful stone varieties to broaden the color and type range available to architects and will offer many more varieties in the future. A list of sources of stone imported into the United States in 1966 gives a hint of the array already available: Argentina, Austria, Belgium-Luxembourg, Brazil, Canada, Denmark, Dominican Republic, Estonia, Soviet Socialist Republic, Finland, France, West Germany, Rock of Gibraltar, Greece, Guatemala, Hong Kong, Iceland, India, Indonesia, Israel, Italy, Jamaica, Japan

South Korea, Lebanon, Malaysia, Mexico, Morocco, Netherlands, Norway, Pakistan, Poland, Portugal, Singapore, Republic of South Africa, Spain, Sweden, Switzerland, Taiwan, Thailand, Togo, Turkey, United Kingdom, Uruguay, and Yugoslavia. Many are small or intermittent suppliers but virtually all those on the list, and other nations which do not appear, have the raw materials to support a large and vigorous industry.

CHAPTER 7.--GEOLOGY AND STRUCTURE OF DEPOSITS

Three primary classes of rocks comprise the crust of the earth: Igneous, metamorphic, and sedimentary (51). The igneous rocks are the most abundant, making up an estimated 90 percent of the crust. However, rocks of all three classes are utilized as dimension stone.

Igneous rocks have generally been regarded as originating by crystallization from melts (magnas) or solutions, although there is wide evidence that the origin of some igneous rock masses can be attributed to recrystallization of preexisting rocks in the solid state without an intervening liquid or molten stage. Coarsely crystalline igneous rocks are attributed to slow crystallization while the finer grained varieties are the result of rapid cooling. In general, slower cooling or crystallization would be attained by formation (crystallization) at deeper levels beneath the earth's surface while the finer grained rocks solidified at or very close to the surface. Examples of coarse (plutonic) igneous rocks include: Granite, syenite, diorite, gabbro, diabase, and porphyries while the finer grained (volcanic) types include: Rhyolite, trachyte, dacite, andesite, basalt, and various glasses such as obsidian and extrusive fragmental rocks such as tuff. It should be mentioned that chemically and mineralogically series of plutonic and volcanic rocks may be identical, differing only in the size or arrangement of constituent grains, such as granite--rhyolite, syenite--trachyte, diorite--dacite--andesite, and gabbro--diabase--basalt. Such groups of chemically similar rocks are called clans (55). Each square in table 7 represents such a clan.

Sedimentary, or stratified, rocks (84) are those originally deposited in layers, or strata (singular-stratum) either on the bottom of oceans, lakes, and rivers (subaqueous sediments) or, less often, on the dry land surface (subaerial sediments). They are composed of grains derived from the mechanical and chemical weathering and disintegration of preexisting rocks (detrital or clastic grains), by chemical precipitation from aqueous solution, or by the accumulation of shells or skeletons of organisms that have secreted calcium carbonate or silica from the water they lived in. The sediments, after deposition, are compacted and cemented until they form a coherent sedimentary rock. Examples of sedimentary rock are sandstone (formed from sand) (105), limestone (from shells, detrital grains, skeletal remains, or precipitated calcium carbonate) (104), and shale (from mud). Sedimentary rocks are systematically classified by mineralogy and grain size. One such classification is given in table 8.

TABLE 7.--Simplified classification of the common igneous rocks[1]

Basic mineralogy...	Dominant type of feldspar	Abundant quartz	Neither quartz nor feldspathoids abundant	Abundant feldspathoids	Rock is mostly mafic silicates: Olivine absent	Rock is mostly mafic silicates: Olivine present
Feldspar, an essential mineral (forming more than 10 percent of the rock)	Perthite or orthoclase	GRANITE <u>Rhyolite</u>	SYENITE <u>Trachyte</u>	NEPHELINE SYENITE <u>Phonolite</u>	(2)	(2)
	Sodic plagioclases	QUARTZ MONZONITE <u>Quartz Latite</u>	MONZONITE <u>Latite</u>	(2)	(2)	(2)
	Medium plagioclases	GRANDODIORITE <u>Dacite</u>	DIORITE (ANORTHOSITE, if over 90 percent felsic) <u>Andesite</u>	(2)	(2)	(2)
	Calcic plagioclases	QUARTZ GABBRO <u>Quartz Basalt</u>	GABBRO (ANORTHOSITE, if over 90 percent felsic) <u>Basalt</u>	(2)	(2)	(2)
Feldspars absent or accessory only (less than 10 percent)		(2)	(2)	(2)	PYROXENITE (<u>Augitite</u>)	PERIDOTITE (<u>Limburgite</u>)

[1]Coarsely crystalline rocks shown in all capital letters; equivalent microcrystalline rocks in capital and lower case letters and underlined.
[2]Numerous rare rock varieties of limited distribution.

TABLE 8. - Simplified classification of the common sedimentary rocks

Cement..........	Secondary, mainly SiO_2 or $CaCO_3$				Primary, mainly clay or derived minerals
Chief detrital grains.	Calcite or dolomite, quartz is less than 50 percent.	Quartz, feldspar is less than 10 percent.	Quartz, feldspar is 10 to 25 percent.	Quartz, feldspar is more than 25 percent.	Quartz, feldspar and rock fragments.
Average grain size finer than sand.	Marl, limy, or dolomitic mudstone; siltstone and shales.	Shale, mudstone, or siltstone.	Shale, mudstone, or siltstone.	Shale, mudstone, or siltstone.	Graywacke, shales, mudstone, or siltstone.
Average grain sand-size.	Limestone or dolostone (dolomite).	Sandstone.......	Feldspathic sandstone.	Arkose..........	Graywacke.
Average grain size coarser than sand.	Limestone or dolostone conglomerate or breccia.	Conglomerate and sedimentary breccias.	Conglomerate and sedimentary breccias.	Conglomerate and sedimentary breccias.	Conglomerate and sedimentary breccias.

Some sedimentary rocks are later squeezed, crumpled, folded and/or heated by tectonic (mountain-building) forces always working within the earth or as a result of deep epigenetic burial beneath later strata. Heat and pressure rearrange and recrystallize the preexisting grains forming new minerals or recrystallizing existing ones forming new rock types known as metamorphic rocks (103). Thus limestones are converted to marbles, sandstones to quartzites, and shales to slates (106). Preexisting igneous rocks are also subjected to metamorphic changes but are difficult to tell from igneous rocks in the strict sense unless stress has altered the intrinsic rock structure so that some alinement of structural elements can be observed. Greenstone, amphibolite, and serpentine are among the more generally recognized metamorphic rocks derived from preexisting igneous forms. Some metamorphic rocks may have originated from any one of several preexisting rocks, and only sophisticated petrologic research will yield clues to their history. Examples of such rocks include gneisses which may have been shale, granite, or arkose; schists which may have altered from sandstone, arkose, rhyolite, diorite, or basalt; and amphibolites and serpentines (include verde antique) which may have recrystallized from basalt, diabase, or impure dolomites. These are only examples, the full range of possibilities is far more complex. A simplified classification of the common metamorphic rocks, based on mineralogy and structure is contained in table 9. There are many ways one can classify metamorphic rocks, but most of these schemata are better left to serious students of matters such as mineral facies, stress-antistress minerals, kinetics of metamorphism, and metasomatism. If one wishes to learn more about this subject, Hans Ramberg's "The Origin of Metamorphic and Metasomatic Rocks" published in 1952 by The University of Chicago Press remains one of the more easily comprehended and well-organized sources.

TABLE 9. - Simplified classification of the common metamorphic rocks

Characteristic mineralogy	Dominant structural characteristic			
	Massive	Banded	Laminated	Foliated
Silicates..........	Metasomatic granites, amphibolite, serpentine, greenstone.	Gneiss.....	Slate......	Schist.
Calcium or magnesium carbonates.	Marble, dolomitic marble.	Banded marble.	Slaty marble.	Schistose marble.
Silica.............	Quartzite...........	Gneissic quartzite.	Slaty quartzite.	Schistose quartzite

The primary classes of rocks have certain genetic characteristics which affect their distribution, lateral or vertical continuity, uniformity, and structure.

Rocks of sedimentary origin, although comprising only about 10 percent of the crust, form the surface rock type over perhaps three-fourths of the dryland area of the earth. They occur, if they have not been subjected to stresses accompanying mountain building, as flat-lying beds or only moderately inclined from the horizontal plane. They exhibit relatively uniform chemical and

physical character laterally and are much larger in horizontal extent than in vertical thickness, reflecting the shape of the sea bottom where most were formed. Vertical character is much more variable, which reflects changing environment of deposition from one time period to the next, than horizontal variation, which reflects events occurring over a wide lateral area at a single moment of time.

Igneous rocks, controlled in their distribution by orogeny (mountain building) tend to occur in elongate belts, with individual related igneous rock bodies alined like beads on a string along the axis of the belt. These igneous bodies have various names depending on their size and origin. A few of the more common types of intrusive or extrusive igneous bodies are: Batholith, a thick plutonic rock body generally extending to an unknown depth with relatively steep sides cropping out over 40 square miles or more; stock, a similar body with an outcrop of less than 40 square miles; sill, an intrusive sheet of approximate uniform thickness and relatively thin compared to its lateral extent; laccolith, a floored intrusive body that has domed up the overlying rocks so that it has a convex upper surface; lopolith, a floored intrusive body that is centrally sunken into a basinlike form so that it has a concave upper surface; dike, an elongate relatively narrow body of igneous rock crosscutting the structure of adjacent (enclosing) rocks; flow, a tabular-shaped body of lava that consolidated from magma on the surface of the earth; sheet, a general term sometimes used for all sheetlike igneous rocks whether a flow, sill, or dike.

Metamorphic rocks in general reflect the distribution of their protoliths--premetamorphic rock from which they have been derived. If subjected to compression, they will be folded and squeezed so that their outcrop will be narrowed parallel to the direction of the stress vector while remaining approximately unchanged normal to the stress. Thus, many of the metamorphics form outcrop patterns tending to parallel orogenic trends and also develop secondary internal strain fabrics due to reorientation of constituent grains to parallel directions of stress relief.

There are several intrinsic diagnostic features for distinguishing between the igneous, metamorphic, and sedimentary rocks. Igneous rocks are characterized by interlocking crystallized grains; by general (but not uniform) abundance of feldspar which is one of the most diagnostic mineralogic features; and of course by the nonoccurrence of fossils. Sedimentary rocks generally show stratification; grains are rounded or fragmental (except if they constitute a chemical precipitate); and fossils are often present. Metamorphic rocks are characterized by parallelism of mineral grains producing banding, foliation, and schistocity. Preexisting pebbles or fossils may be distorted or partly absorbed and diagnostic secondary metamorphic minerals may be present such as garnet or kyanite.

As one can deduce, the origin of a given rock and its subsequent history produce textures (size, shape, and color of constituent grains) and fabrics (structural arrangement and orientation of the grains and how they are aggregated together), which influence durability, strength, porosity, specific gravity, cleavage, hardness, workability, susceptibility to weathering, and even appearance of the rock.

Perhaps the most critical structural features pertaining to dimension stone deposits are the occurrence and distribution of fractures and fracture systems. The most important type of natural fractures are called joints. These are visible open seams that occur at various intervals and limit the size of blocks that may be quarried and provide natural breaks (headers) along which quarrying proceeds and that determine the orientation of quarry operations. They are usually vertical or steeply dipping and even widely spaced, parallel jointing is preferred. Often two systems of parallel joints occur at right angles to each other forming a joint set that is of great convenience to quarrying. Close jointing precludes quarrying of large blocks, permits water and weathering effects to penetrate deep into the rock, and also indicates a history of undue stress which also may have strained the rock in other less obvious ways. If the joints are too closely spaced, or in many crosscutting orientations, the rock is valueless for dimension stone. In igneous rock the occurrence of bedding joints is also important in that it separates the rock into easily quarried, more or less horizontal, sheets or beds. These joints usually approximate in attitude the contour of the rock surface and are believed to result from the release of load on the rock as a result of erosion. They generally decrease in frequency and continuity with depth until eventually they are entirely absent. In some quarries such sheeting or bed jointing is not present.

Incipient or inconspicuous fractures may not be discovered until the quarry block is freed or even finished and their presence may result in much waste. They may or may not be rehealed with secondary minerals such as calcite, quartz, or mica. Their presence may cause finished stone to break under load or cause differential or unsightly weathering. They are variously called cutters, hairlines, vents, starts, or shakes. Faults are fractures in the c rock along which movement of adjacent blocks has occurred. They may include gouge zones of ground rock matter and the rock on either side may be shattered and brecciated for some distance and weathering effects may also penetrate deeply in such a zone. If the trends and attitudes of faulting conflict with the primary joints systems, they may cause discordance of orderly quarry development. If movement along the fault has been substantial, workable stone may have been displaced or entirely offset.

Many sedimentary deposits and some metamorphic rocks such as marble show pronounced bedding. If the stone separates easily along such planes they are called bed seams. These parallel planes of easy separation may occur at varying intervals and offer a convenient means of quarrying layered rock.

Rock cleavage, schistocity, foliation, and subtle variations in rock fabric also influence quarrying and stone dressing. One, two, or more planes due to such factors may be present, each representing directions of varying ease of split. Identifying these planes is essential to the quarryman. The easiest direction of split is termed rift; the second easiest plane is variously called grain, run, or sculp; and the third easiest is head grain. If no head grain is present, the third direction is often characterized as "the hard way." Sometimes in a sedimentary rock certain planes in the rift direction may split more easily than other rift planes. These planes that split more readily than intermediate rift planes may be identified as reeds. A rock without any rift

or grain may be called "liver rock" or by some other local term. In different types of rock, various structural features determine rift and grain direction. In sedimentary rocks, the bedding is almost always the rift with joints or cutters supplying the run or grain. In marble, rift is generally parallel to relict bedding. In granites, rock rift is usually a joint set, with grain and head grain oriented parallel to sheeting or, if present in proper conjunction, oriented to a second set of joints. In slate, the direction of rock cleavage is the rift. In slate the cleavage is the direction in which platy mineral grains have been oriented resulting in closely spaced parallel lamination in the rock. If the planes are not smooth and uniform, or if intersecting cleavage is present, the slate may be unsuitable for dimension use. The second plane of separation in slate is called sculp or grain and is usually perpendicular to the cleavage. It appears as fine striations on the cleavage faces and permits dimensional control of slate blocks. Ribbons in slate are bands of stone of different composition that cross the cleavage at varying angles and represent original bedding planes. They may cause variations not only in color but also in weathering properties.

Modern use of channeling machines, jet piercing, diamond and wire saws has lessened dependence on secondary planes of separation after blocks have been freed along rift, but the astute and conservative quarryman still makes use of all planes present in quarry planning to lessen costs and decrease waste.

There are several other structural features that may be encountered in a deposit which will be of concern to a dimension stone operator. Veins and dikes, which cut the rock mass, are generally objectionable for several reasons: They disrupt the continuity of the rock and quarrying operations and may mar the appearance of the finished stone; if they differ in hardness from the stone groundmass, it may make polishing difficult; they may weather differentially in a finished block; many cause a great deal of waste stone in a quarry because of wall rock alteration; and a finished block or slab may later break along the vein or dike which may not be adequately bonded to the rock matrix. (Generally veins or dikes have been emplaced along healed fracture systems.) On rare occasions veins or dikes can be tolerated or may even be desirable. An example of the latter case is verde antique where crisscrossing veinlets give the stone its characteristic pattern, in this instance the veinlets and groundmass are of approximately the same hardness so that the stone polishes well. In other rare cases, systems of veins or dikes may be oriented so that they can be used as a grain or run direction in quarrying, and what is even rarer, the dike rock itself may be marketable as a second stone product. Inclusions and segregations comprise crystals or aggregates of nontypical minerals, zenoliths (inclusions or remnants of other rock types), septa, lenses or patches of altered or atypical rock, breccia fragments, streaks or knots of minerals, nodules of chert or flint, etc. Generally inclusions or segregations make the stone unsuitable for most uses because their presence may preclude smooth splitting, cause differential weathering or polishing, or cause unsightly stains. On polished or relatively smooth finished stones they may disrupt patterns or be simply aesthetically offensive. A special example of a deleterious mineral inclusion would be the presence of graphite or carbon that destroys the high dielectric constant in slate for electrical uses. The

effect of various minerals present is discussed further under the section on properties and specifications.

Some stones contain "quarry water," or "quarry sap," a name given to water that fills the pore spaces of the rock in its original beds but that evaporates after the rock is quarried. Quarry water contains considerable mineral matter in solution. When it evaporates, the solids are deposited as a cement between the grains, increasing the hardness of the rock, especially at the surface. For this reason, many stones are worked more easily when freshly quarried than after the blocks are seasoned. The presence of this water also explains the damage that may result to blocks if they are subject to freezing right after being quarried.

CHAPTER 8.--APPRAISAL OF DEPOSITS

Only a small proportion of the earth's dry land surface has rock cropping out that will yield suitable dimension stone. Much stone is too deeply buried beneath overburden for exploitation, other stone is physically or chemically unsuitable for use, other stone with proper intrinsic character is not accessible for quarrying operations because of topography, distance from transportation, or other factors. Therefore, careful prospecting, economic evaluation and exploratory work are required to assure a chance of reasonable return on investment before funds are expended on quarry development.

Prospecting and preliminary economic evaluation are really carried out in conjunction with one another since economic considerations often decide where one is looking or will look for a dimension stone deposit. Economic factors guiding prospecting are many. The first and perhaps overriding economic limitation is accessibility, both to transportation facilities and for easy quarrying. Obviously one should not consider a remote mountain peak 30 miles from transportation, unless the stone is an extremely rare and valuable item. In addition, the location of competition and the types of stone these sources can supply and the location and size of markets and distance from the deposit are also critical. If the stone in question is only equal in quality to that which another operator can supply, then the purchaser will generally buy the cheaper stone or the one he is most familiar with. Once it is decided that preliminary economic indications are favorable, active prospecting may proceed

The general geology of an area is a guide to the kind of rocks suitable for dimension stone purposes that might occur. The United States and, in fact most of the world has been geologically mapped in sufficient detail to give at least information on whether the bedrock is igneous, metamorphic, or sedimentary and in many instances on precisely what rock type or sequence occurs in each exact locality. Rock outcrops will reveal a great deal about rock properties even without formal exploration procedures. If weathered stone is removed, a fresh surface will reveal color, texture, and uniformity or variations in these properties. Freedom from cracks, closeness and orientation of joints, faults, cleavage, veins, and bedding planes will reveal much about the size of slabs and blocks that can be removed and about how easy quarrying will be. Even float stone, that is,blocks of loose stone on the surface of the ground, will reveal among other things whether the stone is hard, blocky,

massive, and resistant to chemical weathering. The preliminary examination should also pay attention to such factors as topography, presence of overburden, nature and depth of overburden, and possible quarry sites in relation to natural water drainage, potential waste rock spoilage areas, and haulage grades.

Following favorable results of surficial inspection and sampling, if all indications remain favorable, topographic-geologic mapping and core drilling should be done to completely evaluate the size and character of the deposit. For dimension stone, exploration drill cores are rarely less than 2-1/8 inches in diameter (NX bit size) and usually range upward to a diameter of 5-15/16 inches (7-3/4-inch bit size). These relatively large core sizes are needed to study texture, color, fabric, amenability to polishing or other finishing, and distribution of flaws or blemishes.

Diameter of core recovered is primarily dependent upon rock texture--the coarser the grain size, the larger the core needed. Geologic structure and rock type determine hole spacing. A flat-lying, relatively homogenous sedimentary bed may permit spacing holes on a grid with centers as much as 100 to 500 feet apart. Structural, lithologic, and textural variations in metamorphic rocks such as marble may require closer spacing for judicial appraisal. Most igneous rock deposits are fairly uniform so that wide-spaced drilling will generally serve. In all cases, however, experience is the best instrutor and only after quarrying has begun will the operator know if the geologist's judgment was correct.

Currier (34) has given a schedule of points that must be covered in a report on prospecting and exploration operations as follows:

A. General features:

1. Location of deposit or quarry, name of owner, name of district.

2. Size of quarry (if any).

3. Formation name, stone trade name (if any).

4. History of past operations.

B. Geologic features:

1. Distribution of formation.

2. Stratigraphic position.

3. Thickness of formation and workable portion.

4. Lithological classification and description, notable variations.

5. Petrographic description and classification.

6. Mode of origin and occurrence, form.

7. Major structural elements and attitude, folds, etc.

8. Contact relations to other formations.

9. Texture and fabric: Variation, relation to other features.

10. Fractures and fracture systems:

    a. Joints: Attitude, distribution, and spacing.

    b. Faults: Attitude, displacement, width of shattered or gage zones.

11. Rock cleavage; natural planes of parting, relation to other features.

12. Inclusions and segregations: Distribution, nature.

13. Overburden: Nature, thickness, variability, uneveness of rock surface.

14. Weathering, depth, nature, relation to other features.

15. Surface water: Amount, direction of drainage.

C. Industrial features:

1. Classification: Points of similarity or difference with other commercial stones of its class.

2. Use of the stone, specific structures as examples.

3. Topography.

4. Accessibility.

5. Working facility, structural elements.

6. Workability of the stone, production and milling into finished blocks or other architectural and monumental units.

7. Color, texture, and finishes.

8. Reserves, proven and inferred, areas available for development by potential competitors.

For a detailed discussion of the treatment of each individual point the reader is referred to Currier (34). Currier's outline was devised primarily as a guide for making a surface examination. But, many of the items can be

more fully understood by careful petrographic examination and physical testing of core samples. Pieces of core can be sawed and various experimental finishes and polishes can be tried on the cut surfaces. Also, statistical analyses of flaws and blemishes encountered on such cut surfaces can be made to permit predictions of the frequency distribution, average size, and size range of such imperfections in the entire deposit. Accurate records are made of each hole, and core sections are marked, recorded, and saved for future study and reference. Subsequently, during actual quarrying such records and an orderly core library can be invaluable in planning quarry operations.

CHAPTER 9.--QUARRYING

Quarry Planning

Based upon information gathered by geological studies, physical exploration, study and testing on cores and other samples, detailed market projections, and if capital and other needs can be satisfied, a plan of quarry operations is decided upon. The quarry may be a simple or multiple bench face in a hillside, an open pit, underground room and pillar; an almost infinite number of variations or combinations are possible. The plan is influenced principally by the orientation and thickness of the stone unit to be quarried; its dimensions, dip, internal structural features; and the attitude of individual blocks within the virgin deposit. If the rock deposits to be quarried are flat lying and relatively thin, the quarry will tend to be wide and shallow; if beds are flat lying and thick, deep open pits may result; dipping beds, particularly if they dip beneath waste rock, may require underground quarrying techniques. In many cases internal structures such as orientation of joints, fractures, cleavage planes, or other lineaments along which natural breakage tends to occur will determine the direction from which the quarryman attacks his rock mass. At the same time it is important to plan where rock waste will be piled so that one does not discover years later that it is going to interfere with subsequent quarry operations or offend those who consider a mine or quarry dump as intruding upon the beauty of nature.

Open pits are of two types--the "shelf" quarry and the "pit" quarry. Where the ledge of stone forms a hill, the floor of a quarry worked on hillside may be little if any lower than the surrounding country. In such openings, known as shelf quarries, both transportation and drainage are favorable. Pit quarries are more common. They are sunk below ground level, access is gained by stairs, ladders, or mechanical hoists, and material is conveyed from the quarry, by inclined tracks, trucks, derricks, or cableway hoists. Pits may reach depths of several hundred feet.

Underground mining has several favorable and unfavorable inherent characteristics. Selective mining can be accomplished by following the most desirable beds. No stripping is required and the workers are not exposed to the weather. On the other hand, the cost of making primary openings is high, and much stone must be left for roof support. A method of quarrying known as "undercutting," intermediate between the open pit and the adit, is occasionally used. Channel cuts, or separations made by wire saws or other means along the quarry walls, are slanted outward; thus the floor space is enlarged

gradually. Wings or buttresses of stone may be left at intervals for wall support.

Stripping

"Stripping" is the process of removing soil, clay, gravel, sand, unsuitable stone, and other debris that may overlie the stone horizons to be quarried. In a few places ledges or outcrops of sound, quarriable stone may have been exposed by erosion but in most cases overburden may range from a few inches to 30 feet or more. Methods of removal are governed principally by the type and quantity of material to be moved, distance to be moved, topography, drainage, and attitude and regularity of the surface of the economic stone.

Types of equipment used include hydraulic monitors, bulldozers, dragline scrapers, clamshell buckets, and power shovels. Massive earthmoving machines now available will remove heavy overburden at lower cost than lighter equipment such as bulldozers. Hydraulic stripping is the least costly method, but it can be used only where conditions provide an adequate water supply, favorable drainage to a waste disposal area, and an earthy overburden that can be broken down with a stream of water. If the surface rock is inferior, it may be removed by blasting, but care must be taken to avoid shattering the underlying usable stone. The expense of removing heavy overburden may add substantially to the cost per cubic foot of stone quarried, particularly if the deposit is of limited thickness.

Strain Relief

When stripping is completed the next step is to separate and remove the quarry blocks. In shelf or side-hill quarries the operations are relatively simple. In pit quarries a difficult problem commonly encountered is a condition of strain or compression in the rock mass. If a row of closely spaced holes is drilled in such a mass of rock, it may expand, crush the webs between the holes, and partly close the holes. If this takes place during the drilling process, the drill bit may be pinched and rendered immovable. Before normal quarry operations can be conducted it is imperative that the strain be relieved.

At West Chelmsford, Mass., one method of strain relief that has been used is to drill 52-inch calyx drill holes in a line at right angles to the direction of compression, leaving a web of granite 4 to 6 inches wide between the holes. The expansive force of the rock is enough to crush the webs. An expansion of one-half inch in a mass of rock 100 feet long is common, and a much greater expansion has been noted at times.

A more recent innovation to obtain strain relief requires less cumbersome equipment. A flame drill may be used to cut a channel, relieving the strain in quarry sectors prior to block removal operations. The method, commonly known as jet-channeling, involves combustion of fuel oil with oxygen (sometimes compressed air) and generates a temperature above 5,000° F. Thermal shock disintegrates the rock, and the spalled fragments are blown from the cut. Water is used to cool the burner, and the resultant steam coming from the

burner with the flame jet, combined with combustion products, provides the velocity to force the disintegrated rock particles out of the cut (fig. 14).

Primary Separation

The first step in quarrying exposed rock is to make a primary break or cut that will separate a block of stone from the in situ mass. Joint systems or other natural planes of separation should be utilized as fully as possible, but if such natural planes are not available a cut or fracture must be made.

The softer rocks--limestone, sandstone, and marble are usually cut with channeling machines, wire or diamond saws, or by drilling and broaching; harder or more firmly cemented rocks--granite, quartzite, basalt--may be jet-channeled, wire- or diamond-sawed, drilled and blasted, or drilled and broached. There are exceptions to these general rules, of course, depending on local conditions or individual preferences.

The flame-cutting method known as jet-channeling is the most recent innovation in making primary and other cuts at dimension stone quarries. Generally, jet-channeling is an effective cutting mechanism in rocks rich in quartz, nepheline, and dolomite which favor the spalling process. Granite, sandstone, quartzite, nepheline syenite, and dolostones are typical readily spalled rocks. Limestone, calcite-marble, basalts, gabbros, and slates are not favorable subjects. In most such rocks the abundance of mafic minerals and micas tend to reduce the efficiency of the spalling process, and in the case of limestone and calcite-marble the stone will calcine or fuse and not spall at all.

During operation, the jet blow-pipe may be mounted on a simple frame or even hand-held as it is moved back and forth along the channel. A channel approximately 4 inches wide can be cut eight times faster than if it was drilled and broached, it has been reported. Jet-channeling also results in a relatively straight- and smooth-cut face.

The wire saw is a popular means of making primary cuts. It is used successfully in slate, granite, limestone, and marble quarries (fig. 15).

This equipment consists of a three-strand or single-strand wire that runs as a belt under tension. When fed with sand, aluminum oxide, silicon carbide, or another cutting agent carried in a stream of water, it cuts a narrow channel by abrasion. The wire used is about three-sixteenth of an inch in diameter, making a cut about one-quarter of an inch in width that becomes somewhat narrower as the wire wears. Sand may be used as an abrasive in slate sawing; however, granite is so hard that sand is ineffective as an abrasive, and granular aluminum oxide about 40 mesh or, in some granites, 60 to 120 mesh is used. It is recovered in a sump and reused until worn out. The wires are carried on 5-foot sheaves. To minimize wear on the wire, each wire is 16,000 feet long.

For deep cuts, structural-steel masts 70 or 80 feet high have been designed to carry fixed sheaves at the top of the mast and also to support a movable platform carrying sheaves that guide the wires as they enter and leave the cut. This platform moves down as the cut progresses. Tension is

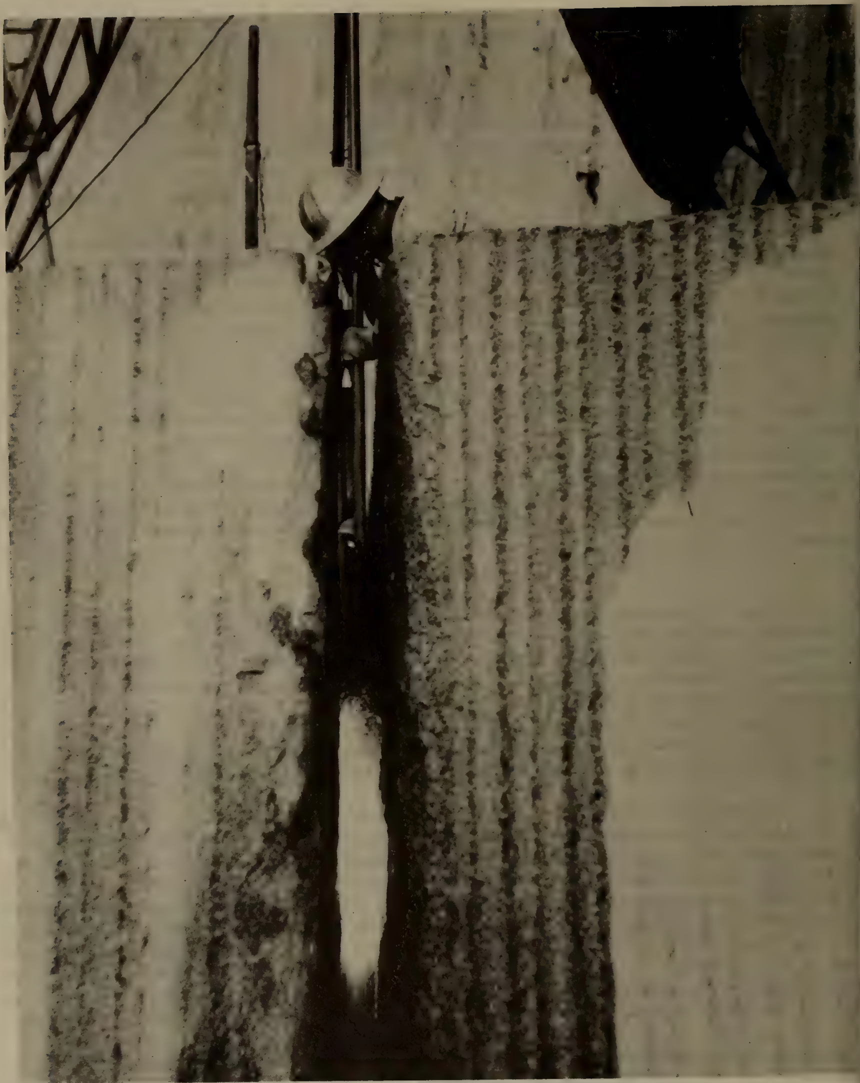

FIGURE 14. - Jet Channeling. *(Courtesy, Rock of Ages Corp.)*

FIGURE 15. - Wire Saw. *(Courtesy, H. E. Fletcher Co.)*

maintained with a car to which weights hanging over the quarry face are attached.

A typical arrangement of the equipment consisted of a gang of four wires spaced 3 feet apart operating on a bench 110 feet wide and 70 feet high. The wires were descending at a rate of $1\frac{1}{2}$ to 2 inches per hour. The wire-cut surface is smooth and requires little if any subsequent finishing except when a polished surface is required. By judicious spacing of the wires, millwork is greatly reduced. For instance, the 3-foot block cut in the quarry simply requires splitting in the center to make two 18-inch curbstones.

Primary cuts in marble, sandstone, and limestone are often made with channeling machines (fig. 16). Such machines operate with chopping action similar to that of a reciprocating drill. The cutting tool comprises several chisel-edged steel bars clamped together. As the machine travels back and forth on a track, it cuts a channel 2 to $2\frac{1}{2}$ inches wide and several feet deep. If the quarry floor is level, track laying is simple. If the beds are inclined, it may be necessary to quarry each bed separately to maintain uniformity. The removal of right-angled blocks from successive, inclined beds results in a notched or saw-toothed quarry floor, which necessitates

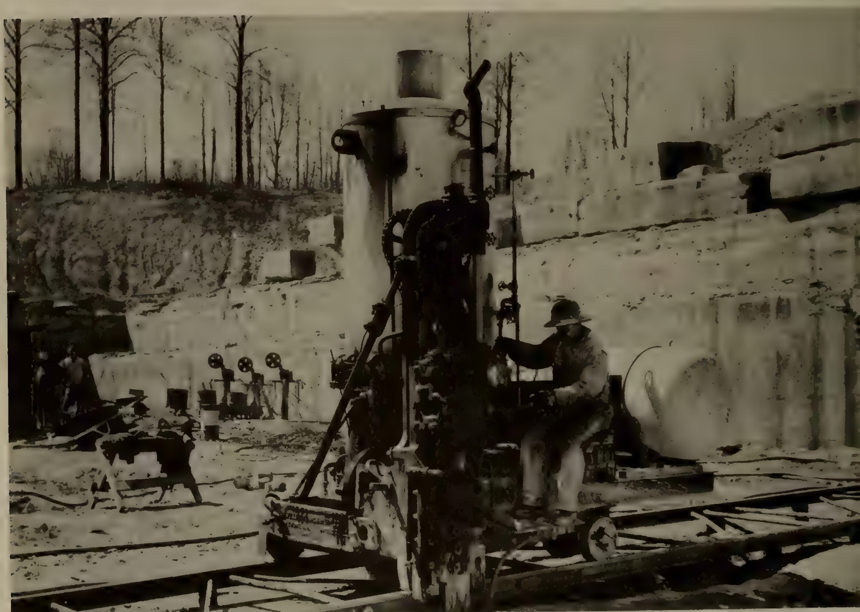

FIGURE 16. - Channeling Machine. *(Courtesy, Indiana Limestone Co.)*

construction of elevated tracks for the channeling machines. An easier method of cutting dipping beds is to place the channeling-machine track on the inclined rock surface in the direction of dip. The force of gravity which tends to pull the machine downhill is overcome by use of a balance weight.

For steeply dipping beds such equipment is not suitable.

To conserve rock many operators prefer to make primary cuts by a drilling and broaching method. Using a reciprocating drill mounted on a bar, deep holes are drilled close together in a straight line. The webs between them are removed with a drill or a flat broaching tool substituted for the drill. Thus a narrow, continuous channel is made. As mentioned previously, any strain in the rock must be first relieved. Hollow drill steel and detachable tungsten carbide bits are commonly used. The amount of drilling accomplished varies with different stones.

As an alternative to broaching, explosive charges may be detonated in the row of drill holes. However, this method tends to give a less even break and the break may be somewhat difficult to control so that the method is now little used.

In very few quarries circular diamond saws may be used for primary cuts where blocks for removal are of limited size. In flagstone and similar quarries in thin-bedded rocks, simple handtools may be used, principally sledges, wedges, mattocks, and crowbars.

After primary cuts are made the stone is free on all four sides and, of course, the top of the block. It may have been necessary to actually cut only a channel along one side if natural planes such as joints had proper orientation and spacing. However, if natural sheeting or parting planes do not occur, the block may still be attached at its base, in which case a process known variously as undercutting, bed-lifting, or floor-breaking may be required. For this step any of the above procedures may be used but perhaps the most common one is drilling a close-spaced line of holes followed by wedging, the so-called plug-and-feather technique.

Feathers are two half-round strips of iron, flat on one side for contact with the wedge and curved on the other to fit the wall of the drill hole. The plug is a steel wedge which is driven between the feathers. The plugs are sledged lightly in succession, beginning at one end of the line to maintain an even strain on the rock. Sledging is continued until a fracture appears.

A natural question is how the first block of stone is removed from the flat floor of a quarry when starting a new bench. In one method, a block about 15 feet square is drilled with closely spaced holes on four sides, which are then channeled. The stone is now free on the sides. A central hole is drilled, the base of which is enlarged by small charges of dynamite. Larger charges of dynamite are loaded, at the same time plugging the central hole with mud. After successive shots, the block is freed, and, of course, occasionally cracked in the operation.

Secondary Subdivision and Trimming

When the larger masses are separated from the solid ledge, the next step is to subdivide them into blocks of the approximate sizes and shapes desired in the finished product or into convenient sizes for removal from the quarry. In this process the natural splitting directions of the rock must be taken into account. Most stones exhibit a tendency to split with greater ease in certain directions than in others.

To obtain the easiest splitting and the smoothest surfaces the major fractures are made in the directions of the easiest split. Compressed-air drills of the hammer type are usually employed to make a row of holes along the line where a break is desired. The holes may be only 4 inches deep and several inches apart. The break is made by driving "plug-and-feather" wedges in the holes until a fracture appears. Thin-bedded or laminated stones can be split by simply prying layers apart or by hammer and wedge work.

The term "scabbling" is applied to a process used at some quarries for trimming blocks of stone to desired dimensions and smooth surfaces. It is particularly important at quarries that ship blocks to distant mills because careful trimming reduces freight charges on waste.

Several methods are employed. Scabbling picks similar to ordinary double pointed miners' picks are sometimes used, but sawing is generally more satisfactory and economical. Diamond-tooth dragsaws or diamond-tooth circular saws may be employed. Scabbling planers are effective substitutes for saws. They consist of two sets of massive vertical blades that scrape off irregularities as the block is dragged between them. Wire saws are used also, enabling several blocks to be lined up and trimmed at the same time.

Block Removal and Yard Service

Most hoist derricks consist of a swinging boom and a mast anchored with guy lines. At some large Ohio quarries, the area covered by a derrick boom, including an area from which blocks of stone may be dragged conveniently, is known as a motion. It is about 130 by 60 feet in area. When the stone in such an area is worked out, the derrick is moved to an adjoining motion. For handling small blocks in shallow quarries, special stiff-leg derricks that can be easily moved are employed. Portable crawl-type-tread or tire-mounted cranes that can move under their own power as quarrying proceeds have replaced derricks in some quarries.

Grabhooks, chains, or cable slings may be attached to blocks of stone to hoist them from the quarry. Grabhooks are the most convenient because, attached by shallow indentations in the block sides, they can lift a block from a position flat on the quarry floor, whereas the block must be raised a few inches from the floor for chains or slings to be passed beneath it. Cable slings are usually regarded as the safest means of attachment.

The quarry blocks and slabs produced in flagstone quarries are usually smaller than those hoisted from quarries in massive sandstone; hence the

hoisting equipment is usually of a lightweight, portable type. Portable equipment is especially advantageous because such quarries tend to be shallow and of large horizontal extent.

In some regions mills are so close to quarries that the derrick may be used to place the blocks on mill transfer cars; however, haulage by rail or truck is usually required. Trucks have replaced railroad cars in many quarries. The term "yard service" relates to equipment and methods used in moving stone from the quarry bank to the mill if such is present or, if not, to trucks or cars for shipment. It also includes piling stone in storage or moving it from storage and handling blocks that are finished in yard operations, such as splitting and finishing curbstones. Derricks and cranes of various kinds, including crawl-type-tread portable cranes are employed. If mill and quarry banks are at different levels, truck or cable-car haulage may be required.

Very small blocks or slabs such as flagging or ashlar may be stacked on wooden pallets in the quarry and then lifted as a unit to a flatbed truck. Waste rock may be raised by bucket from the quarry and simply dumped aside. More and more often, however, it is dumped into a truck for transportation to a crushed-stone byproducts plant.

CHAPTER 10.--SHAPING AND FINISHING

At the finishing plant dimension stones are subjected to various procedures depending upon type of stock, end use, and specifications. Rubble, building stone with rough, irregular faces, requires no finish processing after it leaves the quarry. Other products such as curbing are relatively simple to finish. Building stones of specific dimension or finish and monumental stones are subjected to more complex, multistage manufacture; well-equipped finishing mills are prepared for sawing, planing, jointing, milling, turning, fluting, cutting, carving, grinding, polishing, handling, packing, shipping, drafting, and patternmaking. They include overhead traveling cranes with lifting capacities of 50 tons or more for moving large blocks (fig. 17) and lighter cranes, including some with vacuum lifting devices, for more rapid movement of smaller pieces. Roller conveyors are common equipment for shifting smaller pieces from machine to machine along production lines for standard stock products. Much building stone is furnished on contract for specific jobs and therefore each slab or block is cut for its particular place to exact dimensions. Detailed shop drawings and patterns are a necessity for such orders, and finished pieces are carefully marked to identify their intended position in the building.

Sawing

Quarry blocks arriving at a mill almost always pass first through the primary sawmill, with exceptions as noted later in this chapter. While sawing is more expensive than alternate methods of subdivision, such as plug and feather or the guillotine cutter, it has definite advantages. Thin slabs can be easily obtained--the block can be cut in any direction without regard to internal structure such as rift. This can be important if the most attractive

FIGURE 17. - Lifting a Marble Block. *(Courtesy, Georgia Marble Co.)*

stone surface does not parallel a plane of easy, straight cleavage. Sawing also conserves rock by reducing waste.

Three types of saws are used in modern mills--gangsaws, wire saws, and circular saws.

Gangsaws have been in use the longest time. These saws consist of a series of straight iron or steel blades set parallel in a frame that moves in a backward and forward sawing motion (fig. 18). The blade may be fed with

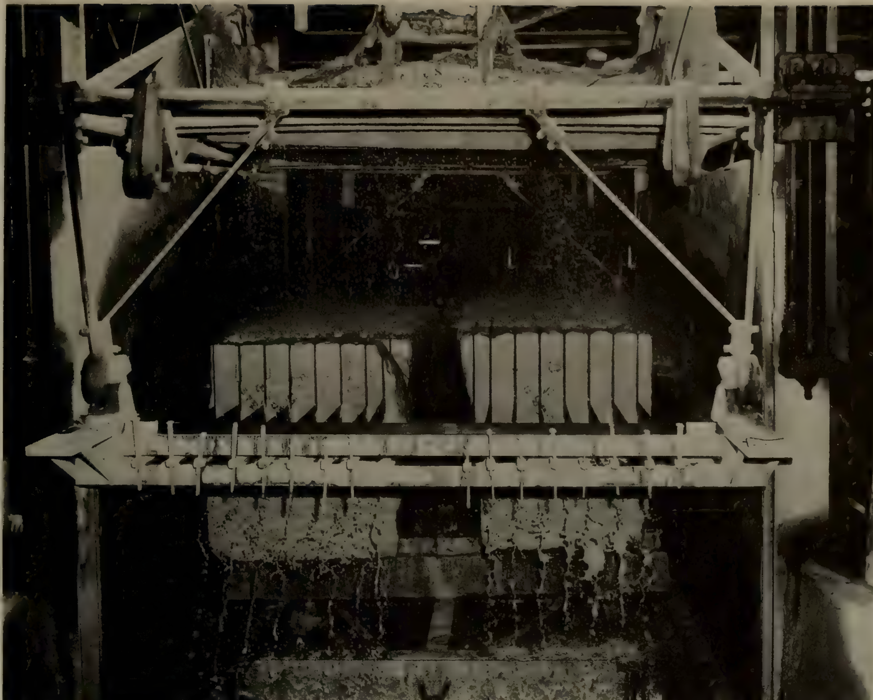

FIGURE 18. - Gangsaw. *(Courtesy, Indiana Limestone Co.)*

steel-shot, sand, chat, aluminum oxide, or other granular abrasives in water or the blade may be set with diamond-impregnated segments. The blades can be set to make parallel cuts of any desired spacing and the gangsaw may consist of up to 40 to 50 blades. For harder stone, such as granite, six to 20 blades per saw are more common to attain the best cutting rate. Typical cutting rates reported range from 3 to 8 inches per hour in granite, using steel shot in water to 15 inches or more per hour with a diamond-set gangsaw in limestone. Blades may range in width from 1-1/4 inches to one-eight of an inch. A 1/8-inch thick blade makes a fairly smooth-walled cut three-sixteenth of an inch thick. If granular abrasives are used, the abrasive and water are collected in a sump and recirculated to the saw blade. To place and remove stone from beneath the gangsaws, a system of transfer and gang railcars is generally used. The transfer car, which runs on a depressed track in front of the gangs, is provided with a short section of track across the top. A smaller gang car on the transfer car is loaded with a block of stone and when the transfer car is positioned before a gangsaw, the gang car is rolled onto tracks running

beneath the saw. The procedure is reversed to remove sawed pieces from the gangsaws.

Sawing is conducted in some mills with single or multiple wire saws using silicon carbide or aluminum oxide abrasives. The cutting tool is a three-strand or single-strand wire running as a belt under tension and fed with the abrasive carried in water. The cost of wire sawing per square foot of surface obtained is considerably higher than when gangsaws are used, but they do offer compensating features. The cut is so narrow (about one-quarter of an inch) that it conserves stock, and the wire leaves such a smooth surface that there is a considerable saving in time and cost to the operations that follow. Cutting rate generally will range from 12 to 40 inches per hour depending upon rock hardness and the abrasive used.

Circular saws of several types have been used. Saws up to 11 feet in diameter using steel shot or silicon carbide as the cutting agents are still used but they have been largely superseded by the circular diamond saw. Saws with individual diamond teeth proved unsatisfactory because of diamond loss due to setting (matrix) wear, but with the introduction of the sintered rim consisting of metal impregnated with numerous small diamonds, the diamond saw became a satisfactory tool (fig. 19). Sizes of available diamond saw blades generally restrict the size of blocks that can be cut to those no more than 36 inches thick; they find wider use for subdividing slabs and in trimming, shaping, and joining. Diamond sawing is the fastest and most accurate of the various sawing methods in general use. Blades are expensive and easily ruined by careless use.

Surfacing

Where rough quarry stock is dressed into building stones without sawing, the first step in manufacture is termed "lining," which consists in working the edges of the block to the required dimensions. This is usually done with pneumatic tools. The next step is to dress the faces to the edge dimensions. This is generally done with a surfacing machine, which essentially consists of a reciprocating tool covered with blunt projections. As the machine is guided over the surface it chips off fragments of stone, gradually working the surface down to an even plane. A heavy tool is used to remove the larger irregularities, and a lighter tool with smaller projections is used to give a tooled-surface finish. The exposed face, if desired, may be left with a rock-cleft surface.

A planer is a machine provided with a cutting blade having both vertical and angular adjustment. A traveling bed or platen carries the stone and moves back and forth beneath the tool. On each pass a thin layer of stone is scraped from the surface. The edge of the planer blade may have a varying number of corrugations to the inch yielding a tooled surface with parallel grooves. A reversible-head planer will plane the surface during both forward and backward movements. The tungsten carbide edged blades may be cooled by a stream of water to prevent overheating.

FIGURE 19. - Circular Diamond Saw. *(Courtesy, Georgia Marble Co.)*

A split face is produced by means of a guillotine which is simply a heavy blade under pressure which is pressed upon a stone until it splits along a relatively straight plane.

Grinding and Polishing

For finishes smoother than sawed, hammered (by surfacing tool or by hard tool), cut, or quarried face, it is necessary to rub, grind, and polish to the required degree.

If heavy blocks are to be ground or polished, the blocks from the surfacing machines or mill saws are placed in groups of eight or 10 on a timber bed with their upper surfaces on an even plane. The group of blocks is framed with timber and cracks between blocks and the frame is filled with plaster of paris. Rubbing, grinding, and polishing may then proceed, using the various stationary stone methods described for slab finishing below. Because almost all grinding, rubbing, and polishing is done on slab, with very little block being so refined, the operational detail is presented for processing slabs.

One method to square and finish slab is the rubbing bed where stone is held on the surface of a 10- to 14-foot-diameter cast-iron disk rotating on a vertical axis. Sand carried in a stream of water serves as the abrasive, and surfaces are worn to desired dimensions and smoothness. Most surface grinding however, is now done on a production-line basis. Slab grinding machines utilize stationary grinding heads usually up to 6 feet in diameter. Slab is carried beneath the head on a platen-type belt conveyor and a single pass beneath a grinding head may remove one-eighth inch of stone or more, depending on stone hardness, feed rate, and whether diamonds or other abrasives are used. Succeeding slab grinders on the strip grinding and polishing line will use finer abrasive with vitrified gritting stones (using silicon carbide or aluminum oxide) shellac hones or felt buffers with compounds such as tin oxide, depending on ultimate finish (fig. 20).

Another very versatile type of grinder is the automatic gantry-type slab machine. This utilizes one or two 22- or 27-inch heads, known as scrolls which traverse a stationary slab or slabs held in a work bed. The standard machine setup will cover a slab or slabs up to 6 by 14 feet. The machine is automatically cycled to move over the workpiece in a preset pattern. Successively finer abrasives or abrasive-set inserts are used depending upon finish.

The conventional radial-armed grinding-polishing machine (fig. 21) requires an operator to move the spindle over the stone surface. Successively finer abrasive-set insert segments or abrasives are used, followed by fiber or felt buffer pads for final polishing if required.

Special Products and Finishes, Carving, and Lettering

Curbstone and house veneer are generally broken to size and shape in yard operations. When quarry blocks have been delivered, they are generally broken to size with a hydraulically actuated descending blade known as a guillotine or by a similar machine known as a stone cutter which is set with a row of teeth 1 or 2 inches wide. Modern curbing plants use a jet torch to spall off irregularities, sharp edges, and corners after splitting to size. This reduces damage to vehicle tires which may strike the curbstone after it is placed in use. This so-called "flame textured" finish is also of increasing popularity for exterior and interior panels and veneer (fig. 22). Veneer and strip rubble, after cutting, must have its ends dressed or squared and the faces pitched. In pitching, the edges of the stone face are cut back to form an irregular convex surface of more pleasing appearance. Pitching may be done with hammer and chisel, or with a pitching machine. The machine uses two swing hammers each tipped with replaceable tungsten carbide inserts. The

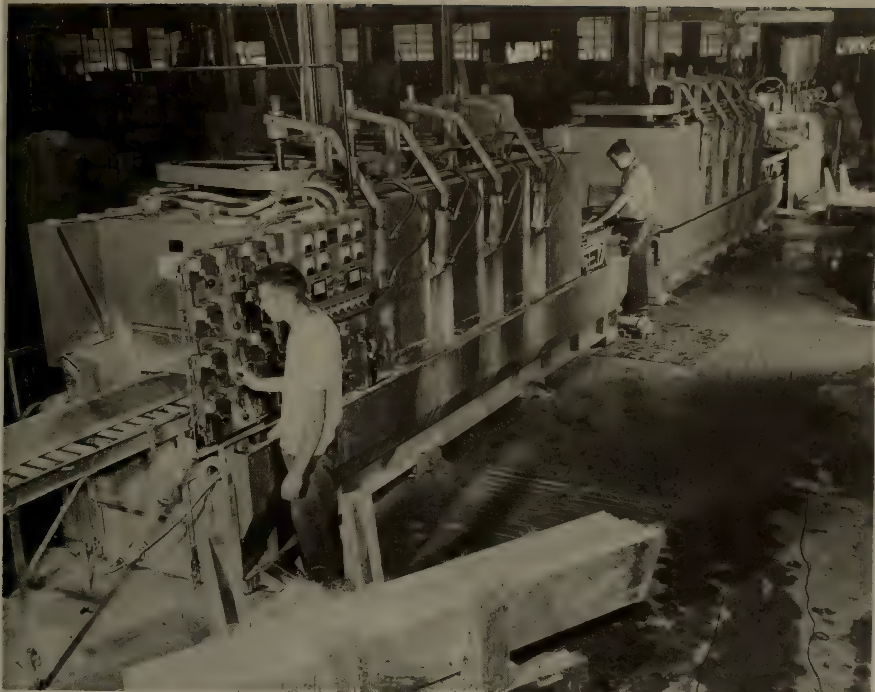

FIGURE 20. - Strip Polishing Machines. *(Courtesy, Vermont Marble Co.)*

stone is conveyed through the machine, and the hammers strike blows parallel to the long axis of the stone, chipping the face edges away.

A special preliminary shop operation is coping and jointing. Coping is the process of cutting slabs to finish working thickness, and jointing is the process of trueing the edges with the face, and squaring the ends and sides to finish working dimensions without chipped corners. Diamond wheels are largely used to buff the sides in jointing operations in place of silicon carbide wheels formerly used.

Not all dimension stone is used as orthogonal units. For special shapes, special shaping devices must be used.

Stone columns are widely used in architecture. They comprise two types--sections set one upon another and monolithic columns. Sectional columns are generally cut with steel drums rotating on a vertical axis. Sand or steel shot may be used as cutting agents, or the lower edge of the drum may be

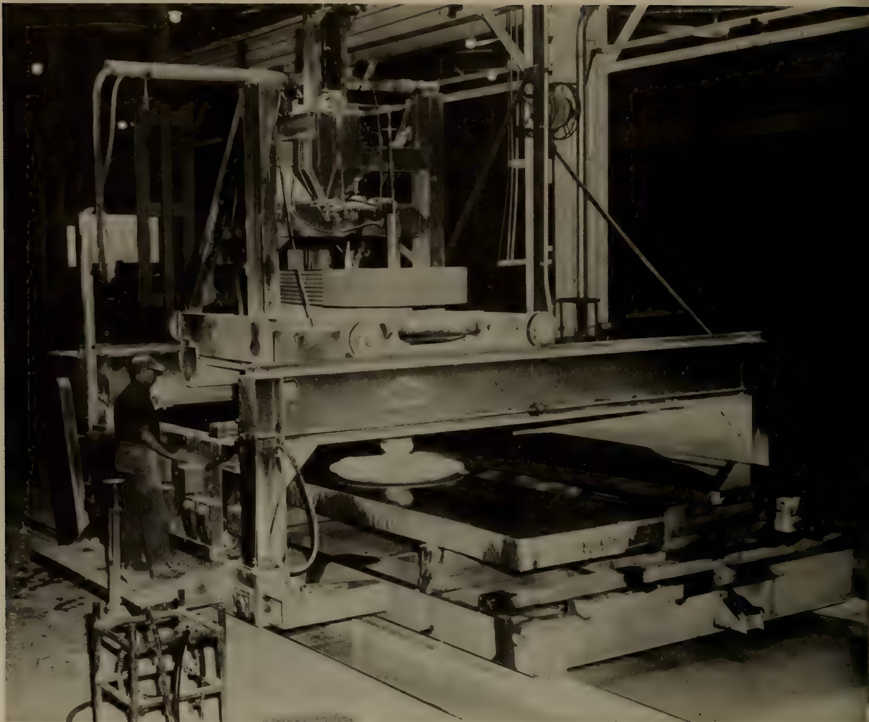

FIGURE 21. - Polishing Granite. *(Courtesy, Rock of Ages Corp.)*

mounted with diamond teeth. For monolithic columns a lathe is used. The column is roughed out to approximate dimensions before it is placed in the lathe. As the column rotates, it is shaped with a tool similar to that used on an ordinary machine lathe for turning metal shafts. Actuated by a worm gear, the tool travels back and forth, cutting a little deeper at each motion until the desired diameter is reached. This process is followed by rubbing and polishing. Other forms such as vases and balusters are also turned on lathes.

To make fluted columns, the stone is first turned in a lathe to the desired diameter. While the column remains stationary in the lathe, the cutter, held in the tool post, travels back and forth from end to end of the column until a groove is completed (fig. 23). The column is then turned to new positions and the process is repeated until all the flutes are made. Flutes are sometimes cut with carborundum or diamond wheels.

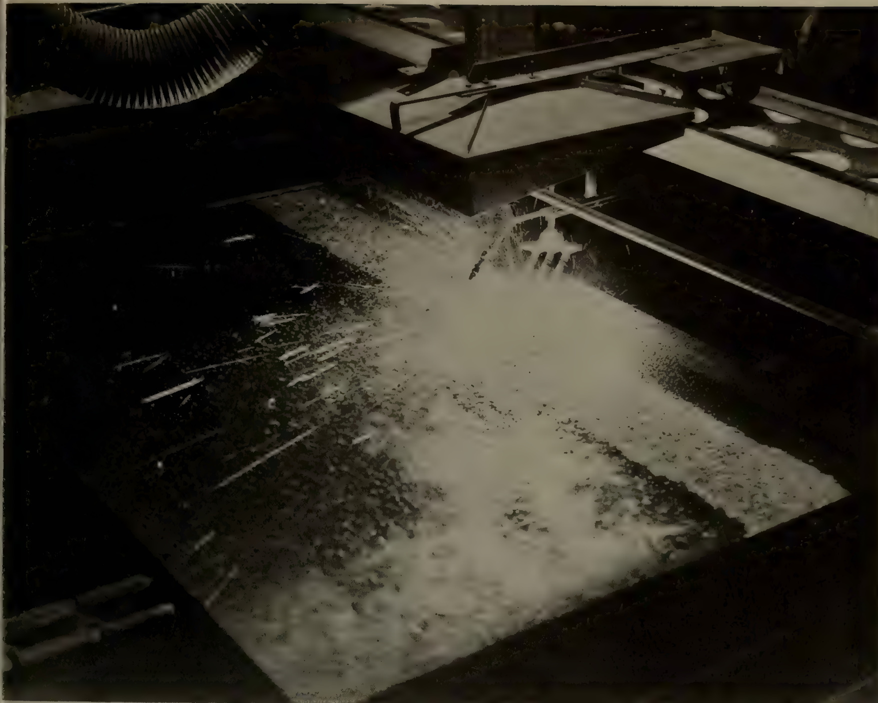

FIGURE 22. - Flame-Texturing Granite. *(Courtesy, Cold Spring Granite Co.)*

Wire saws are used to cut irregularly shaped blocks. These saws are smaller shop machines and work in a way analogous with band saws in woodworking. Planers are also adjustable to cut curved forms; shapes such as moldings or cornices are made in this fashion. Silicon carbide or diamond wheels may be used in like fashion and pneumatic chisels or hammers are also used to shape complicated patterns and irregular designs. A milling machine with a rotating cutting head is used to cut recesses and other intricate shapes.

Carving, lettering, and sculpting have been considered the fine art portion of stone finishing. At present, however, little carving and lettering is done by hand or even with pneumatic tools. Now the stone surface, on which inscriptions or designs are to be cut, is masked with a rubber sheet. Lettering or other designs are imprinted on the coating; and, with a sharp tool like a scalpel, the coating is removed from all parts that are to be cut below the surface. Where uniform lettering is needed, the process is simplified by using a die for each letter. A hammer blow on a hot die outlines the letter with double cuts that pass through the coating to the stone surface. A sharp spatula is used to pick out the pieces of mask between the cuts.

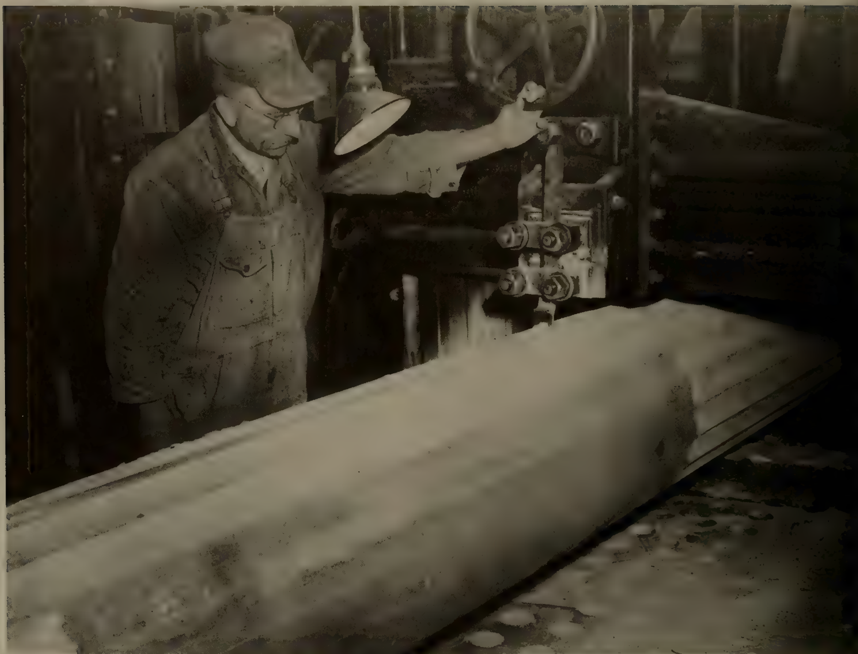

FIGURE 23. - Cutting Flutes. *(Courtesy, Vermont Marble Co.)*

Stone thus prepared is placed in an illuminated closed chamber, with the surface to be carved in a vertical position and facing the operator who observes it through a window. A nozzle, through which compressed air at a pressure of 80 to 100 psi drives a stream of fine sand, powdered silicon carbide, or aluminum oxide, is held through a curtain, which protects the operator from the abrasive dust. When the sand blast is directed against the design, the exposed stone is quickly cut away, and the sand has little or no effect on the surface coating. Certain parts of letters or designs may be cut one-half inch to 1 inch in depth. Design cutting may be done in successive stages. Remarkable precision and fineness of detail are possible.

Designs that would require long and tedious work with hand or pneumatic tools are cut by sandblasting in a few minutes.

Sculpturing remains an operation for master craftsmen who are actually artists. The major concession to mechanization in statuary and similar sculpturing is that pneumatic tools have largely replaced hand chisel and hammer.

FIGURE 24. - Splitting Slate. *(Courtesy, Pennsylvania Slate Producers Guild, Inc.)*

In marble shops an important finishing operation is the repair and classification department. Cracks and blemishes in blocks or slabs are filled with resins or wax, colored to match the stone, and the stone is classified by grade depending upon color, soundness, and degree of imperfections. If a slab is broken, it may be repaired by imbedding rods in it and by cementing slab and rods with resins or other adhesives. Refinishing as necessary is then completed.

Slate requires a specialized finishing procedure. Slabs are split by wedging parallel to the slaty cleavage (fig. 24) and either diamond-sawed or sledged to approximate size in other dimensions. Final shaping of roofing slate consists of splitting with thin chisel and mallet and trimming either by saw or with a straight-blade trimming machine. Millstock slate products are generally sawed to size with a circular diamond saw in all dimensions.

Blackboards are made of true-splitting slate taken from thick beds. They are split on the natural cleavage to a thickness of three-eighths of an inch, and the surface is generally so smooth and true that it requires only a final polish. Blocks for structural uses are split to approximate thickness plus enough material to permit finishing to a true surface on both sides. Unless the original split-face finish is wanted, the slabs are first worked to a smooth surface on a planer. The planer bed travels back and forth in the same manner as a saw bed. The tool consists of a heavy blade set horizontally and adjustable laterally and vertically. When planed to a smooth surface, the slab is turned over and the other side planed almost to the desired thickness, but allowance must be made for slight reduction in thickness during later processes of rubbing and honing (fig. 25).

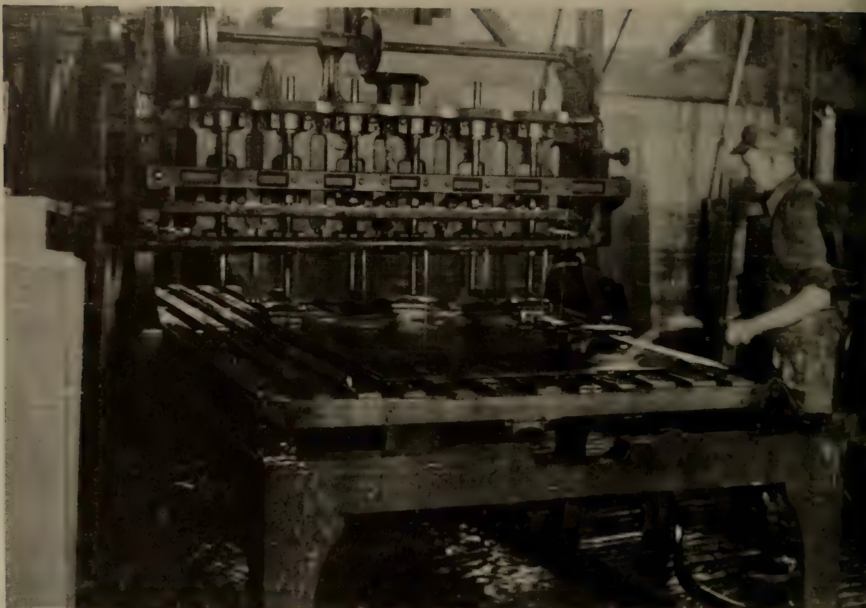

FIGURE 25. - Finishing Slate. *(Courtesy, Pennsylvania Slate Producers Guild, Inc.)*

CHAPTER 11.--TRANSPORTATION AND HANDLING

Finished or dressed dimension stone is at once a fragile and high unit-priced item. As a consequence it not only requires careful handling but can also afford the high charges resulting from such specialty transportation. I recent years new innovations have reduced breakage and other damage and have cut costs at the same time. The three principal sectors of transportation ar handling are (1) quarry and quarry to mill yard, (2) mill yard and mill, and (3) mill to consumer.

In the quarry, both portable crawl-type-tread or tire-mounted cranes anc fixed boom and mast derricks are used for hoisting stone. Because the quarried blocks are rough and not yet trimmed to finish dimensions, some chipping and abrasion is permissible. Grabhooks, chains, or cable slings are the common means of attachment. For transport to the mill, rail-flat cars or flat-bed trucks are most often used. The stone blocks are laid upon wooden blocks or logs on the car (or truck) bed or on metal supports so that the blocks car be more easily unloaded. Very small blocks or slabs such as flagging or ashlar may be stacked on wooden pallets in the quarry and then lifted as a unit to a flat-bed for transit. At the mill-yard stone may go directly to milling

procedures or may be stacked in the yard by portable crane, fixed crane, or overhead traveling crane for later finishing.

In the mill process proper, overhead traveling cranes with lifting capacities of 50 tons or more do the heavy lifting and moving. The unique transfer and gang car handling system used at the gangsaws has been described in the section on shaping and finishing. For smaller pieces and within finishing shops lighter overhead cranes find wide use. Some of these attach to slabs by vacuum lifting devices to avoid chipping the stone which by now is close to or at finish dimensions and has had much labor value added. Roller conveyors are common equipment for shifting pieces from machine to machine along production lines for standard items.

Finished stone, if in small sizes, is palletized for shipment to consumers. Thin veneer panels, in particular, can be carefully stacked with dividers to prevent rubbing and can be shipped in this manner with relatively little rehandling required. Larger pieces are placed individually on flat beds, often on individual pallets or are framed in wood to facilitate later rehandling with less chance of damage. Stones with polished or other specially finished surfaces, of course, require extra care to avoid damage to the finish as well as the usual avoidance of chipping or cracking.

The trend is toward increasingly specialized service for transportation of finished products from mill to consumer. Truck beds and railroad flatcars specifically designed for delivery of stone and other heavy products are being used. Special bulkheads and flanges prevent vibration of the items in transit and facilitate unloading.

The 1963 Census of Transportation yields the following data on shipments of cut stone and stone products:

	Distribution, percent
Means of transport:	
Motor carrier	46.8
Private truck	39.2
Rail	13.9
Water	.1
Means of transport (ton-miles):	
Motor carrier	59.8
Private truck	26.3
Rail	12.3
Water	1.6

Distance of shipment (miles):	Distribution, percent
Less than 50	18.7
50 to 99	21.7
100 to 199	42.5
200 to 299	9.9
300 to 399	4.2
400 to 499	2.3
500 or more	.7

Weight of shipment (pounds):	Distribution, percent
Less than 1,000	0.7
1,000 to 9,999	10.0
10,000 to 29,999	19.6
30,000 to 59,999	34.3
60,000 to 89,999	11.5
90,000 or more	23.9

Weight of shipments (pounds):	Distribution (based on ton-miles shipped), percent
Less than 1,000	1.5
1,000 to 9,999	15.1
10,000 to 29,999	14.9
30,000 to 59,999	41.1
60,000 to 89,999	10.1
90,000 or more	17.3

CHAPTER 12.--QUARRY AND PLANT WASTE DISPOSAL AND SITE REHABILITATION

Even if quarrying and finishing are conducted with utmost care, much waste stone is an unavoidable end product of dimension stone operations. Recovery of usable stone usually is less than 50 percent of the rock quarried, generally no more than 25 to 40 percent, and occasionally as low as 10 to 15 percent. The lower recovery figures are more typical of certain slate quarries and of memorial granite operations where inferior stone or beds must be quarried because of their close association with the commercial stone. This byproduct stone may be overlying strata, intercalated beds, or blocks of the quarried stone that contains knots, lenses, schleiren, cracks, veins, or other imperfections. Other blocks may be broken in handling. After arriving at the finishing plant and yard, additional waste is generated by such operations. Ends of blocks, saw and planer cuttings, spalls, rock sand, and similar small bits and pieces remain to be disposed of. Very fine waste rock flour mixed with waste abrasive results from grinding and polishing.

At one time quarry and mill waste was simply cast aside into what developed into huge spoil piles. These piles were not only unsightly, but often they had been placed above valuable rock making it uneconomical to quarry. The rock dust and used abrasive was allowed to drain freely into local streams with resultant damage to aesthetic values.

These practices are now changing. Waste quarry and mill water is now impounded in large settling lagoons where rock and abrasive flour settle out before the clarified water runs off into surface streams. A typical settling basin may be 450 feet long, 100 feet wide, and 12 feet deep. It must be cleaned of deposited sediment about once every 2 years. If certain abrasives such as silicon carbide are contained in the sediment, the basin may give off copious bubbles of gas resulting from the decomposition of the abrasive in water.

Sand accumulations at mills, or that obtained by crushing, grinding, and screening coarser waste may be sold as building or paving sand, engine or furnace sand, or for various other industrial uses. Waste fragments of good quality may be shaped into ashlar for veneer, sold for flagging, or crushed for coarse aggregate, roadstone, or railroad ballast. Large irregular waste blocks may be used as riprap for shore and harbor protection or in spillways at dams. Marble and limestone waste are most readily marketed because of the wide variety of chemical, metallurgical, and physical uses to which they may be put.

Important crushed-marble or limestone products are terrazzo chips used extensively in flooring and chips for stucco wall finish. Waste blocks may be cut into convenient sizes for ashlar used in increasing quantities in house construction. In some places, waste limestone or marble is manufactured into lime. It is also ground to an impalpable powder (marble flour) for use as whiting and as a constituent of stock feed and fertilizers. It is sold as agricultural limestone, for chemical and industrial uses, and in crushed form for concrete aggregate and roadstone.

It has been found that pulverized slate is a useful filler in road asphalt mixtures, roofing mastic, linoleum and oil cloth, paint, and various other products, but up to 1965 only small quantities were used for this purpose. Slate roofing granules are made in large quantities, but relatively little is derived from waste at quarries producing roofing and millstock.

Some slate has adequate bloating properties for making lightweight aggregate of good commercial quality.

Laboratory tests indicate also that waste slate and steel-mill slag mixed in equal proportions may make a satisfactory raw material for mineral-wool manufacture. Addition of magnesian limestone in place of slag may also give a satisfactory product.

Another potential use is for making slate-lime brick. Slate, ground to a powder, is mixed with 10 percent of lime, pressed into bricks, and cured for 7 hours at 150-pound steam pressure. The laboratory product compared favorably with sand-lime brick in strength and other properties.

If waste utilization is promoted aggressively, returns from sales of byproducts may become important items in maintaining a favorable profit margin for dimension stone operators.

In recent years there has been an increasing demand for worked-out underground mines and quarries for storage of both liquids and solids and for warehousing and record centers. Easily controlled temperature and humidity as well as security from theft, fire, or atomic attack are among the advantages of such sites. Rental or lease of the rooms or galleries in the depleted quarry or mine offers potentially large profit to the owner. Even open-cast quarries may be sealed and roofed over to store various liquids such as petroleum products. Open quarries are frequently put to later use as emergency water reservoirs for drought periods. During the mid-1960 drought years in the Northeast more than one town was grateful to have an old waterfilled quarry which previously had been a local eyesore, lovers lane, or dumping ground for abandoned autos. Other waterfilled quarries were used for recreation such as boating, swimming, or fishing. Others have been used as town dumps and eventually were filled and became valuable real estate while disposing of trash. Other quarries in areas where hills were leveled actually increased land values after stone removal by creating improved land contours for eventual development. All in all, an intelligent, forward-planning stone operation need not create vast waste piles, contaminate streams, or leave nothing but holes in the ground. Proper planning can result in marketing almost all the stone removed and then putting the remaining cavity to constructive or productive use.

Old waste piles already in existence are more of a problem since the individual stones may be so closely locked in place that it costs more to break down the pile than to quarry virgin broken stone. This problem will,to some extent,solve itself as suitable crushed stone becomes scarcer and more expensive near urban areas. Eventually the cost of hauling virgin stone a greater distance will make the old waste piles economically attractive, at which time they will become sought after as crushed stone sources.

One problem in reclamation of new quarry and plant waste is the fact the quantity of waste generated annually at most individual operations does not justify the capital expenditure for equipment and facilities to process and market the waste rock. One logical solution to this problem is for dimension stone operations within one local district to supply their waste to a centrally located processor. The processing facility may be jointly owned by the stone producers or an independent operation dependent upon the stone firms for their raw materials at a price level and in such quantities to permit profitable handling.

CHAPTER 13.--USE TECHNOLOGY

Veneers

The use of thin slab veneers of dimension stone has become widely popular in recent years. Stone veneers are generally less than 2 inches thick and may be less than 1 inch thick. Most popular thicknesses are seven-eighths of an inch, 1¼ inches, 1½ inches, and 2 inches. The use of veneer stone gradually evolved as architects began extending interior thin wall facings and trim from corridors and lobbies to entrances and first floor fronts and eventually to complete exteriors. As one would expect, time-proven methods for installing

interior veneer was extended, with only relatively minor changes, to exterior thin veneer use. For exterior use, however, moisture resistant cement mortar must be used in joints. Wire anchors fastened into mortar-filled pockets in the backup walls are the accepted anchorage system. The metal anchors are supplemented with close-spaced spot bonds of Portland cement mortar. In some cases solid backup grouting may be used. In addition, at every story level, the veneer is supported by continuous horizontal metal shelf angles or a series of metal clips securely fastened to the building frame or masonry wall. Other angle supports are placed above doors and window openings and similar breaks in the veneer.

Panel Wall (Curtain Wall)

Historically, all exterior building walls were load bearing, but with the arrival of skeleton steel or concrete frame construction, the need for thick, heavy, load-bearing walls came to an end. By supporting floors on columns, girders, and beams, exterior walls became nonload-bearing curtains extending from floor to floor. The so-called curtain wall retains two primary functions: (1) To protect the interior and its occupants from the elements, such as heat, cold, rain, and dirt, and from sound, odors, and intruders and (2) to present an attractive exterior appearance. Other materials can serve for such purposes but none can serve the latter function as aesthetically and elegantly as dimension stone. Stone also has natural resistance to weather, fire, corrosion, and it ages gracefully. Typically stone is used as a component in a 2-inch-thick bonded sandwich panel. Such a panel may consist of a 7/8-inch-thick stone facing, a 1-inch-thick insulating core, and a hard-board or metal backing. Some panels may have as much as 2 inches of stone and up to 2 inches of core and backing. A great variety of insulating core materials can be used and they may be fastened to the facing with adhesives, clips, or foamed or poured in place. The ideal core material would have the following properties:

1. Low heat transmission;
2. incombustible;
3. corrosion, rot, and fungus resistant;
4. nonabsorbent;
5. lightweight;
6. nonsagging;
7. nonsettling; and
8. low vapor transmission rate.

Among the popular core materials are resin-impregnated paper honeycomb, resin-impregnated asbestos honeycomb, polystyrene foam, foamed glass, cement-bonded fiber board, and autoclaved cellular concrete. Three types of adhesives are important in sandwich construction: Elastomers, resins, and inorganic cements.

Curtain-wall panels must be set with joints sufficiently large to compensate for vibration, thermal changes, wind loads, and material tolerances. Sealant must then be added to prevent leakage.

The basic panel-wall construction systems in use are: Spandrel, mullion, grid, and sheath. The various systems are named for the way in which the sheathing is placed. The spandrel type has panels placed side by side with joints vertical. The panels are alined on each story so that architecturally the horizontal line is dominant to the eye. Supports are not a primary element of expression. The mullion system has the mullions clearly expressed between panels so that the vertical line is dominant. Between the mullions, each story consists of one panel and a window. In the grid system, both vertical and horizontal support members are clearly expressed so that both lines are architecturally equally dominant. In addition to the vertical mullion lines, prominent horizontal lines extend across the building above and below each panel or window. Sheath-type installations have neither vertical nor horizontal lines prominent. Panels may be square and placed in grid fashion or elongate with long joints vertical.

Various types of adjustable fasteners are used to fasten panels to the structure or, if supporting frames are used, to fasten the panels to the supporting frame and the frame to the structure. In steel structures, angles or brackets are generally used and in concrete structures inserts to take brackets or angles are generally cast into the concrete. A single fastener is usually capable of carrying the weight of an entire panel. Through the use of slotted holes and shins, the supports and panels can be adjusted in three directions: vertical, horizontal, and in-and-out (front to rear). By this means the curtain-wall components can be easily alined during installation.

To prevent infiltration of water and to preserve insulating effects, joints are sealed. Materials used must adhere to the sides of the joint for the life of the panel and be elastic enough to allow for thermal changes. Oil base calking compounds, synthetic plastic or rubber-base calking compounds, tape sealants, and rubber or plastic gaskets are all used in various instances.

Ashlar

Ashlar and ashlar veneers are, as previously defined, small blocks of stone laid in regular or uneven courses or laid at random. They are generally installed with mortar cement similarly to brick work or cinderblock but are occasionally laid up dry (without mortar) for garden walls and similar rough work. The ashlar blocks may have rough (rock-faced), split, planed, or sawed surfaces. The blocks may be regular (rectangular cut to definite dimensions), rough, random, rustic (split to rough dimensions), broken (also called random fieldstone or webwall) in irregular shapes, or tumble stone (with rounded boulder or cobblelike appearance). Rectangular ashlar, the true ashlar in the strict sense, is furnished in specific dimensions. Bed thickness is usually 3, 3-1/2, or 4 inches. Lengths are semirandom but generally range from 1 to 5 feet. Heights of the stones, measured vertically on the face,are designed to permit matching of stones when they are lain in uneven courses (fig. 26). Basically these series are the so-called 11-inch modular and 8-inch modular

FIGURE 26. - Split-Faced Sandstone Ashlar Used in a Residence, Wooster, Ohio. *(Courtesy, Briar Hill Stone Co.)*

ashlar. The 11-inch modular ashlar has, as a basic course, a 10-1/2-inch block plus one-half of an inch of mortar. Other block sizes in 11-inch modular ashlar are 2-1/4 inches, 5 inches, 7-3/4 inches, and 1 foot, 1-1/4 inches. These may be used in various combinations to build the basic 11-inch course. That is, 2-1/4 inches plus one-half of an inch of mortar plus 7-3/4 inches plus one-half of an inch of mortar is equal to 11 inches. The 1-foot, 1-1/4-inch block is of course an oversize equal to 10-1/2 inches plus one-half of an inch of mortar plus 2-1/4 inches. Eight-inch modular ashlar is similarly used in sizes 2-1/6 inches, 4-5/6 inches, 7-1/2 inches, 10-1/6 inches, and 1 foot, five-sixth of an inch. The basic course is a 7-1/2-inch block plus one-half inch of mortar. These two popular sizes are not the only ones available, finer or coarser ashlar can also be ordered. The 7/8-inch, 2-1/4-inch, 5-inch, 7-3/4-inch series which yield a finer textural effect for use in smaller jobs, fireplaces, room dividers, etc., are one example. Ashlar construction is very old; for example, the pre-Columbian Indians of the Southwestern United States used flaggy sandstone without mortar for walls and other structures in the uneven course, rough ashlar method.

The rough, random, or rustic ashlar is furnished with stone grouped in height ranges. An example would be 20 percent, 1½- to 3-inch height; 50 percent, 3- to 6-inch height; and 30 percent, 6- to 9-inch height. For such rustic ashlar the mortar joints must also vary in height to even the courses. Typically, the joints may range from one-half of an inch to 1½ inches in height.

Broken ashlar is generally furnished in specified average and maximum size. Typical broken ashlar would average 4 square feet of face with a maximum 12 square feet, with pieces generally roughly rectangular in overall aspect with spear-shaped or very platy pieces avoided. Joints are of variable width.

Tumble stone ashlar has a boulder or cobblelike aspect and is usually furnished to specified average and maximum size such as 3-inch average and 9-inch maximum diameter. Again, joints are variable as necessary to fit the range of stone sizes.

Interiors

Stone in an unlimited variety of textures, colors, and types gives architects a wide choice for both decorative and functional purposes in nearly every design concept. Beauty, long life, and negligible maintenance costs make stone the logical choice for many interior applications particularly in prestige buildings. As for exterior use, interior dimension stone has adapted to competition from cheaper, less durable building materials by changing to thinner gage panels and veneers and new installation techniques. The lighter stock is easier to handle, generally costs less per square foot of surface, and yet retains traditional appearance, quality, prestige, and value appeals. Among the many interior uses of dimension stone are wall facings, floors, counters, thresholds, sills, stairs, column facings, window stools, toilet and shower partitions, bathroom and powderroom vanity tops, fireplace and room divider facings, kitchen counter tops, and trims of all kinds. One of the major advantages of interior stone is low maintenance cost, but in addition important post-construction dividends accrue from reduced buyer resistance and occupant pride and satisfaction.

For interior use, stone's primary functions are decorative. Since stone in this instance serves no major structural purpose and is not exposed to the vagaries of the elements, more fragile or less resistant stone can be used indoors to create an aesthetic effect. The latter can be enhanced by a variety of pleasing finishes, which includes higher polish, and by setting-in fashions, such as book or diamond matching (see fig. 2), which highlight unique patterns or textures. Some interior stone, particularly decorative marbles, may be waxed or filled with other materials to fill voids and other flaws. In addition, reinforcing rods are embedded or backing is employed quite freely.

Interior stone panels and veneers are generally about seven-eighths of an inch thick. Thicker sections may be required for counter tops, partitions, etc., generally on the order of $1\frac{1}{4}$, $1\frac{1}{2}$, or 2 inches. For some purposes, such as small 12- by 12-inch floor or wall tiles, sections may be as thin as three-eighths of an inch. Ashlars for interior use are the same size as those for exterior use.

Interior stone setting is similar to exterior stone setting, except that less heavy hardware is required. Metal anchors and ties in combination with plaster of paris, cement, or plastic adhesives are commonly used. "Setting space" is the distance between the rough wall backing to the finished face of the stone. Normally this space is $1\frac{1}{2}$ inches unless liners are used in which case $2\frac{1}{2}$ inches are required. Anchors, dowels, and other supports should be of noncorroding metals such as brass, bronze, or stainless steel. Calking, cementing, and cushioning materials should also be nonstaining.

Flagging

Flagging, flat stones used to pave terraces, patios, courtyards, walkways, and similar locales, are generally sandstone or slate. Other stones, however, are also used.

Flagging is laid on concrete, sand, or earth base. Those placed on sand or earth are apt to become uneven with the passage of time, but they have a pleasant informality and releveling, if desired, is not difficult. Ribbon slate which is less expensive than clear slate will last longer if it is not laid directly upon an acidic soil; it is best laid on a sand or concrete base. A concrete base makes the most durable bed, permits a more even surface, and uses thinner flagstones.

Flagstones may be purchased in irregular shapes or may be squared off in sizes ranging from 12 by 12 inches to 54 by 54 inches. Smaller squares (such as 6 by 6 inches) are also sold but tiles are a better term instead of flagstone for these smaller pieces. Squared flagstones are more expensive but far easier to lay than irregularly shaped ones. Common thicknesses are 1-1/2 inches or 1 inch for laying on sand or earth base and three-quarters of an inch for laying on concrete. For placing on sand or earth, it is important that the base be equally compacted and that it support the flags at every point. Soil, mossy soil, or sand are used for filling joints and cracks. A concrete slab requires a perimeter footing below the frostline if the installation is an outdoor one. Slab thickness is usually 3-5/8 to 5-1/2 inches of reinforced concrete depending upon expected traffic and nature of subbase. Mortar is spread for each flagstone or tile as it is laid. For best adhesion, each slate should be buttered on the back with neat portland cement and the mortar bed should be dusted with dry cement. Stones are leveled and alined by pounding into the mortar bed, adding or taking away mortar as required. The joints are then packed with mortar to seal the installation.

Monuments

Monuments are generally set on footings, pedestals, or foundations to stabilize the stone in the desired attitude. The base of the foundation must be below the local frostline. It may be composed of the same stone as the monument proper, of different stone, concrete, or concrete with a stone cap. To prevent tipping by vandals or nature, the monument may be jointed to the base by mortar or by rods mortared into both pieces.

For inscription lettering and other onsite decorating, portable sandblast outfits are used. Using sand or carborundum with compressed air, inscriptions can be cut in the field using techniques similar to those in stone-finishing shops. The only difference is that, instead of the stone being encased in a canvas tent, the worker is furnished with protective clothing and air filters to avoid injury from stone and abrasive dust.

Slate Roofing

Laying slate on roofs is another end use which requires mention. Slate is the most enduring roofing material known but must be installed by trained and experienced roofers. A standard slate roof can be laid watertight without felt but roofing felt beneath the slate provides several advantages. It has considerable insulating value, forms a cushion for the slate, and protects the roof while slate is being installed. Additional insulating value may be gained by using laths over the felt and beneath the slate to obtain an air-space. It would seem almost unnecessary to mention that there should be no through joints from the roofing boards through to the felt surface. Joints should be well offset or, if more than one layer of felt is used over the roof sheathing, well overlapped.

Slate is applied using large-headed copper, zinc, chrome-iron alloy or brass slating nails of necessary length and weight. A rough rule of thumb for length is twice the thickness of the slate plus 1 inch. Three, four, or six penny nails are used as required. The heads of slating nails are not driven home but left with the heads just clearing the slate so that the slate hangs on the nail. A nail driven too far will cause the slate to shatter around it and the slate will tear loose; if not driven far enough, the nail will crack the overlapping slate above.

Technical terms one should be familiar with are "square," "lap," and "exposure." A "square" of slate is one sufficient to cover 100 square feet of roof with a standard 3-inch lap. The weight of a square will vary from 650 pounds for 3/16-inch thick slate to 8,000 pounds for slate of 2-inch thickness. On a flat roof, slate is laid over waterproof bedding layers without lap, the ends and sides butted close together so the amount of slate required to cover a "square" of roof surface is correspondingly less.

"Lap" or "headlap" means the overlap of the slate with the second course below. "Exposure" of a slate is that portion not covered by the next course above and is thus the length of shingle exposed to the weather and view. The proper exposure is considered to be the length of the slate minus the lap divided by two. For instance, the exposure for a 24-inch long slate is 24 inches minus 3 inches equals 21 inches divided by two equals 10½ inches of exposure. For certain roofs or in certain geographical areas 2- or 4-inch lap may be used. In general, the steeper the roof or the milder the climate the less lap required. Details of flashing, or finished hips, valleys, saddles, ridges, etc. are too technical to discuss in this report.

Maintenance and Cleaning

By observing simple maintenance procedures, stone will retain its original finish and beauty throughout many years of use. Neglect or polluted atmosphere may dull or stain the finish of the stone, but if the stone has been properly selected and installed, its ingrained beauty and structural strength can seldom be seriously hurt. Depending upon the stone, finish, and environment it is exposed to, various methods of maintenance and cleaning are required. The ideal procedure is, of course, to keep the stone clean so that

harmful atmospheric agents do not get a chance to do their work. However, this is not always practical so that more drastic measures, other than clear water, may be required. Two special cautions to be remembered are that acids should never be used to clean the calcium carbonate rocks (marbles, limestones, travertines, and onyx) and abrasives should not be used on polished stones. The National Bureau of Standards has published many pamphlets on stone cleaning and maintenance and so has the Marble Institute of America (57, 66, 69).

For polished stone, a mildly alkaline soluble cleaner containing no corrosives is recommended. The stone should be rinsed thoroughly with clean water and dried with chamois to prevent streaking. For exterior use, regular applications of carnauba wax or colorless waterproof lacquer will help to protect polished surfaces from erosion by atmospheric agents. For honed, sanded, or rougher finishes a mildly alkaline, caustic-free abrasive cleaner may be used. It should be free rinsing and the abrasive grit softer than the stone so it will not grind or scratch. Exterior stone can be steam cleaned and joints repointed periodically. If seriously discolored and stained, wet aggregate, hydroair or sandblast cleaning is called for. Sand, glass beads, or other fine iron-free abrasives should be used. For some stones (such as limestone) sandblasting should be avoided if it is at all possible.

Some of the more porous honed or sand-finished stones (such as oolitic limestone or sandstone) may be treated with a water repellent for exterior use. The water repellent helps maintain a clean surface and preserves stone beauty by sealing the exterior pores to infiltration. A minor additional advantage is to prevent water from entering pores and freezing there. The three common treatments are with stearates, silicone resins in a solvent, and sodium methyl siliconate in an aqueous solution.

Stone floors and stair treads must be cleaned regularly in a fashion that will not leave a slippery film. Since these surfaces are subjected to abrasive wear in normal use, abrasive cleaners can be used without too much concern about scratching the surface. It must be thoroughly rinsed and then mopped dry. For more frequent sweeping, various sweeping compounds such as moistened sawdust are satisfactory.

For certain varieties of stains or especially deep-seated ones, various special stain removers are recommended. Many organic stains will respond to treatment by hydrogen peroxide. Sodium hydrosulfite or oxalic-acid will clean rust stains. Alcohol, ammonia, carbon tetrachloride, and various bleaching powders are all useful reagents for special purposes. Oil and grease stains repond to solvents such as a mixture of acetone and amyl acetate or a mixture of fuller's earth and benzine. Paint and varnish staining may require a paint remover. The list could go on and on, suffice to say for each stain there is a method of treatment. However, for all stain removal an expert should be consulted first since some of the reagents mentioned might damage certain stones or finishes if improperly used.

Occasionally it may be necessary to restore the finish over small stone areas. The basic principle is to use abrasive hand bricks or coated abrasive papers in successively finer and finer sequences until a very smooth,

scratchless finish (honed) is achieved. If polishing is required, a final rubbing with tin oxide or other polishing compound will usually suffice. For large refinishing jobs the advice of an experienced stone contractor is recommended.

In summary, it should be repeated that it is easier to keep stone clean than to clean it once it is dirty. Washing with clean water, particularly corners and other places where dirt accumulates will reduce long term maintenance requirements. When painting, plastering, or other construction is conducted nearby, protecting exposed stone surfaces by tarpaulin or other method will also avoid later necessity for stain removal or possible refinishing.

Some stones are more resistant to staining and weathering than others. But in our highly industrialized environment proper care and maintenance of all stones will pay off in longer stone life and increased aesthetic values. The question often arises as to the durability of different types of building stone. Some stones such as granite weather by slow disintegration, others such as marble dissolve slowly. In all standard building and memorial stones, however, these processes are extremely slow and, if sound stone is properly installed, under average conditions visible changes will not appear for many decades.

CHAPTER 14.--GEOGRAPHIC DISTRIBUTION OF THE INDUSTRY

Production

The production trend for dimension stone has, in a broad sense, followed the vagaries of the national economy. It departs in one respect from this pattern, however, in that dimension stone shows wartime production declines. This is due to wartime diversion of investment and economic expansion into strategic necessities from nonstrategic fields such as construction of office buildings, schools, banks, libraries, and other nonessential construction (which are often heavy dimension stone users). Construction that is undertaken is of an urgent nature during wartime and is built by methods using lighter and more rapidly emplaced materials than dimension stone. Expanded use of dimension stone shows in immediate postwar periods as nonessential construction is renewed and backlog needs are filled.

The general trend of the economy, however, has outpaced dimension stone. Recovery for dimension stone after World War I was fairly complete but post-depression and post-World War II recoveries never regained expected levels. Since the early 1930's consistently lower quantities of building stone have been used except for slate and miscellaneous stone. Post-World War II recovery was less than one would have anticipated had not other factors restricted the market. For example, competing materials have gained greater shares of an expanding total market and construction methods have changed. Stone sells for a higher weight-unit price but less stone is used per building. Instead of heavy stone blocks, concrete structures are faced with thin slabs and many buildings are faced with materials other than dimension stone. In the memorial stone field, smaller stone monuments or bronze plaque markers have increased in popularity. Generally higher quarrying, milling, and marketing costs have also required stone prices to remain high.

The change in materials use and construction practice since before World War II has been extremely marked. Steel, concrete, ceramics, glass, plastics, and exposed aggregates are widely used in building facings. Due to durability, appearance, and strength, stone is still used in facing for high-quality or prestige buildings but usually it is used in the form of a thin veneer facing instead of structural load-bearing blocks. The veneer slabs and panels may be fixed and keyed upon steel or concrete and in so-called "curtain-wall" structures the slabs or panels are attached to the steel or reinforced concrete framework without any backing--concrete, brick, or otherwise. Such practices have reduced the weight and volume of dimension stone used in a building of given size to a fraction of what it was when solid masonry construction was practiced.

As the market changed and contracted, many small quarries were abandoned; but many of those that have sustained operations now produce more than they ever did, despite the overall volume decline in the industry.

Roofing slate revived less after each war than the average production for other dimension stone because it was more drastically affected by substitutes. Roofing slate demand was affected as early as 1917 by asphalt base-granule faced shingles.

In the most recent decade, tonnages of dimension stone produced have remained relatively stable with unit values creeping upward. In order of magnitude, sales of stone by variety are granite, limestone, sandstone, slate, marble, basalt, and miscellaneous stone (table 10).

Much of the granite and slate tonnage and some of the marble is monumental, flagging, and curbing; and if such uses are deleted, dimension building stones in order of popularity are limestone, granite, sandstone, miscellaneous, marble, basalt, and slate. In 1966, building stone (including roofing and millstock slate) was 69 percent of dimension stone sold or used; monumental stone was 13 percent; curbing, flagging, paving blocks, and miscellaneous slate was 18 percent (table 11). Approximately 87 percent of all dimension stone was used, in some way, in construction. Paving block sales have nearly vanished due to substitution of concrete, and curbing has declined less severely. Monumental stone declines were caused more by smaller memorials rather than by fewer units. Loss of potential markets to bronze plaque memorial gardens have less impact than would seem likely because such cemeteries purchase large statuary groups, fountains, and other theme pieces which sell at a high price and are almost always carved in dignified and high-status dimension stones, particularly marble or granite. Memorial stone sales tend to increase during wartime contrary to the building-stone trend which is partly due to casualities from the conflict and partly due to increased psychological awareness of the possibilities of meeting death unprepared.

TABLE 10. - Dimension stone sold or used by producers in the United States, by kinds

Year	Granite		Basalt and related stones		Marble		Limestone (including dolomite)		Sandstone (including quartzite)		Slate		Miscellaneous stones	
	Quantity (thousand tons)	Value (thousand dollars)	Quantity (thousand tons)	Value (thousand dollars)	Quantity (thousand tons)	Value (thousand dollars)	Quantity (thousand tons)	Value (thousand dollars)	Quantity (thousand tons)	Value (thousand dollars)	Quantity (thousand tons)	Value (thousand dollars)	Quantity (thousand tons)	Value (thousand dollars)
1930	1,330	$22,036	39	$75	282	$12,339	1,937	$19,296	675	$5,755	174	$6,216	78	$230
1931	1,032	18,259	21	22	196	10,020	1,117	11,240	344	3,228	138	4,186	22	85
1932	648	11,743	13	19	179	7,297	641	7,151	180	1,524	75	1,906	157	604
1933	477	7,951	10	12	150	6,237	551	6,542	103	1,073	73	1,516	30	369
1934	543	8,686	11	13	82	3,195	586	3,621	113	988	67	1,642	28	284
1935	536	7,996	31	20	57	3,228	723	3,022	107	991	104	2,341	14	262
1936	667	11,097	37	42	98	5,533	805	4,918	162	1,656	165	3,838	39	520
1937	751	11,452	25	28	95	5,135	714	5,309	232	1,721	168	4,027	64	687
1938	673	9,778	22	22	89	4,973	704	4,937	166	1,474	144	3,165	112	595
1939	734	9,838	101	53	124	6,305	1,061	6,678	196	1,956	180	4,101	83	723
1940	658	10,088	22	21	89	4,795	1,082	4,260	172	1,427	154	3,436	83	827
1941	782	10,831	10	18	69	4,370	814	3,780	183	1,428	181	4,410	89	967
1942	522	9,081	13	17	49	3,452	463	2,144	232	1,113	107	2,956	68	895
1943	284	7,991	125	119	43	3,079	237	798	100	667	73	1,946	41	712
1944	284	9,129	18	17	52	3,867	162	623	74	659	61	1,721	29	559
1945	362	8,981	204	230	60	4,705	334	2,505	64	737	70	1,972	35	690
1946	535	16,712	50	70	77	7,081	504	5,878	160	2,328	96	3,420	47	902
1947	522	19,281	39	71	86	9,273	543	7,221	188	3,656	113	5,077	42	1,426
1948	639	22,323	58	77	83	9,105	607	10,583	203	4,167	141	6,867	80	1,768
1949	485	21,315	35	98	102	11,153	680	12,671	227	4,661	132	6,400	90	1,850
1950	555	22,767	37	107	89	9,406	808	17,804	266	6,135	169	7,571	104	2,244
1951	532	23,222	33	114	87	8,905	807	18,327	292	7,247	171	8,008	112	2,355
1952	519	22,397	58	138	89	9,279	787	15,061	352	7,579	146	6,587	91	2,565
1953	597	23,792	58	216	76	8,431	799	15,496	354	8,635	153	6,685	65	2,742
1954	634	24,505	52	358	85	9,855	1,174	19,854	401	9,946	152	6,349	35	2,579
1955	617	23,772	60	216	116	12,535	1,182	24,599	504	12,239	141	6,582	55	2,633
1956	540	25,943	72	331	105	12,098	1,029	20,696	624	14,406	119	6,802	146	3,197
1957	539	26,442	61	480	149	14,072	953	20,981	555	11,864	120	6,620	79	3,229
1958	621	24,059	122	571	136	15,631	979	18,757	489	11,313	115	6,431	60	3,492
1959	654	26,588	14	377	137	18,085	952	20,693	473	11,745	119	6,365	93	3,718
1960	600	28,773	14	365	129	17,743	860	17,140	439	11,541	119	6,319	96	4,128
1961	662	30,569	13	462	157	18,566	855	16,738	391	11,134	124	6,749	113	3,872
1962	902	32,012	103	649	146	18,739	896	16,847	390	10,904	151	7,441	141	4,095
1963	753	32,796	93	620	150	21,002	895	18,134	412	11,443	153	8,055	160	4,268
1964	843	33,752	45	633	130	19,245	779	18,944	431	10,615	164	9,086	153	4,695
1965	786	33,135	26	787	126	17,277	732	17,172	396	10,787	182	9,276	155	3,801
1966	626	33,847	37	695	83	14,419	728	18,270	405	10,103	166	9,173	282	3,307

TABLE 11. - Dimension stone sold or used by producers in the United States, by uses

Year	Building		Rubble		Roofing slate		Millstock slate		Monumental[1]	
	Quantity (thousand tons)	Value (thousand dollars)	Quantity (thousand tons)	Value (thousand dollars)	Quantity (thousand tons)	Value (thousand dollars)	Quantity (thousand tons)	Value (thousand dollars)	Quantity (thousand tons)	Value (thousand dollars)
1945	382	$5,485	390	$549	38	$976	12	$742	251	$11,361
1946	707	13,768	293	650	56	1,983	12	1,033	300	17,435
1947	739	18,610	269	715	64	3,095	14	1,445	312	19,815
1948	981	24,909	276	574	82	4,566	12	1,600	307	20,541
1949	916	29,910	339	709	68	3,760	13	1,728	258	18,758
1950	1,229	36,665	247	615	74	4,099	15	2,130	237	17,824
1951	1,237	38,827	253	591	78	4,357	17	2,127	230	16,851
1952	1,199	35,354	320	827	54	3,068	17	2,050	230	17,117
1953	1,148	35,380	403	1,126	53	3,006	17	2,221	251	18,995
1954	1,534	42,729	390	904	44	2,401	18	2,378	235	18,105
1955	1,687	51,685	375	1,372	46	2,568	21	2,747	234	16,843
1956	1,579	50,785	470	1,588	40	2,589	20	3,114	235	18,016
1957	1,612	51,287	373	1,628	33	2,003	23	3,227	247	18,942
1958	1,551	50,059	303	1,139	33	2,020	24	3,113	236	17,257
1959	1,443	55,998	360	1,606	29	1,810	21	3,110	236	17,862
1960	1,316	52,953	330	1,743	25	1,611	23	3,053	221	19,254
1961	1,240	54,767	424	2,143	31	1,796	26	3,202	226	18,770
1962	1,320	55,133	537	2,022	30	1,767	30	3,529	227	19,246
1963	1,332	55,680	620	2,687	32	1,965	30	3,825	277	24,099
1964	1,475	58,351	391	2,041	33	2,228	28	3,951	241	20,464
1965	1,343	53,303	355	1,859	24	1,872	28	3,871	266	20,902
1966	1,136	52,374	528	1,879	23	2,243	26	3,675	252	22,096

Year	Paving blocks		Curbing		Flagging[2]		Total[3]	
	Quantity (thousand tons)	Value (thousand dollars)	Quantity (thousand tons)	Value (thousand dollars)	Quantity (thousand tons)	Value (thousand dollars)	Quantity (thousand tons)	Value (thousand dollars)
1945	2	$22	13	$204	41	$481	1,128	$19,820
1946	5	50	31	544	66	929	1,471	36,392
1947	5	56	52	1,110	77	1,124	1,531	45,970
1948	3	33	63	1,382	87	1,285	1,812	54,891
1949	2	28	59	1,689	96	1,565	1,750	58,146
1950	4	51	78	2,430	136	2,220	2,024	66,036
1951	3	52	83	2,872	128	2,500	2,029	68,178
1952	2	38	86	2,576	133	2,577	2,036	63,608
1953	2	40	83	2,500	144	2,729	2,101	65,996
1954	1	18	128	3,408	184	3,502	2,534	73,446
1955	6	127	121	3,916	184	3,317	2,674	82,576
1956	6	88	120	3,551	166	3,194	2,636	82,925
1957	4	84	122	3,575	222	3,298	2,635	84,044
1958	101	475	128	3,095	146	3,096	2,522	80,254
1959	29	144	155	3,811	169	3,230	2,442	87,571
1960	31	131	157	3,929	154	3,335	2,257	86,009
1961	76	295	149	3,859	143	3,261	2,315	88,093
1962	264	937	155	4,236	166	3,817	2,729	90,687
1963	4	86	153	4,026	168	3,950	2,616	96,318
1964	6	163	168	4,682	203	5,090	2,545	96,970
1965	5	109	157	4,708	225	5,611	2,403	92,235
1966	5	158	156	4,689	201	5,121	2,327	89,814

[1]Includes small quantities for precision plates.
[2]Includes slate for miscellaneous uses.
[3]Figures by individual use may not add to total due to rounding.

A large proportion of dressed and polished building stone is used for facing the exterior street floor of large buildings and in lobbies and hallways. For these status-adding purposes many of the more exotic patterns and colors have become much sought after. For exteriors, granite gneiss and irridescent black and dark gray granites have been widely used; for interior, brecciated and folded marbles and onyx add much to the decor. Travertine has been of recent renewed popularity both for polished interiors and dull-finished exterior slabs. Onyx and marble in thin translucent sheets recently have been increasingly favored as light-transmitting panels in place of ordinary windows or stained glass. None of these special types of stone is separated in Bureau of Mines statistics and therefore quantitative trends cannot be shown.

Large blocks of stable, flaw-free stone have also gained in recent years for precision plates but for this end use also the Bureau of Mines does not maintain a complete separate record.

As dimension stone operations are gradually becoming more completely mechanized with concomitant reductions in operating costs, the products may become more and more successful competitors with less labor intensive construction materials in the future. Leading producer States are: For granite, Texas, Georgia, Massachusetts, North Carolina, Minnesota, and Vermont; for limestone, Indiana, Wisconsin, Minnesota, and Missouri; for marble, Vermont, Georgia, Tennessee, Missouri, and Alabama; for sandstone, Ohio, Pennsylvania, New York, Tennessee, and Colorado; for slate, Pennsylvania, Vermont, Virginia, and New York; for basalt-type rocks, Washington and Pennsylvania; and for miscellaneous stones, Virginia and California. The production is essentially national in character; in 1966 the only States not reporting dimension stone production were: Alaska, Delaware, Idaho, Kentucky, Louisiana, and North Dakota (table 12). At least some of these have reported intermittent dimension stone production in the past and almost all have potential stone resources.

TABLE 12. - Dimension stone sold or used in 1966 by producers in the United States, by States and variety
(Thousand short tons and thousand dollars)

State	Granite			Basalt and related rocks			Marble			Limestone (including dolomite)			Sandstone (including quartzite)			Slate			Miscellaneous stones		
	No. of plants	Quantity	Value	No. of plants	Quantity	Value	No. of plants	Quantity	Value	No. of plants	Quantity	Value	No. of plants	Quantity	Value	No. of plants	Quantity	Value	No. of plants	Quantity	Value
Alabama	-	-	-	-	-	-	2	([1])	([1])	1	([1])	([1])	-	-	-	-	-	-	-	-	-
Alaska	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arizona	-	-	-	-	-	-	2	([2])	$7	-	-	-	21	7	$99	-	-	-	-	-	-
Arkansas	-	-	-	-	-	-	2	1	110	-	-	-	5	38	218	-	-	-	-	-	-
California	5	19	$654	-	-	-	1	([2])	8	2	([1])	([1])	6	2	35	2	2	$36	19	224	$649
Colorado	4	1	35	-	-	-	1	([2])	13	1	([2])	$1	22	12	223	-	-	-	1	([2])	1
Connecticut	5	3	58	-	-	-	-	-	-	-	-	-	3	([1])	([1])	-	-	-	-	-	-
Florida	-	-	-	-	-	-	-	-	-	1	2	35	-	-	-	-	-	-	-	-	-
Georgia	34	169	3,857	-	-	-	1	([1])	([1])	-	-	-	1	([2])	11	-	-	-	-	-	-
Hawaii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	15	104
Idaho	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Illinois	-	-	-	-	-	-	-	-	-	3	5	129	-	-	-	-	-	-	-	-	-
Indiana	-	-	-	-	-	-	-	-	-	18	440	11,737	9	([1])	([1])	-	-	-	-	-	-
Iowa	-	-	-	-	-	-	-	-	-	4	12	220	-	-	-	-	-	-	-	-	-
Kansas	-	-	-	-	-	-	-	-	-	7	21	648	1	([2])	6	-	-	-	-	-	-
Kentucky	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Louisiana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maine	10	10	1,386	-	-	-	-	-	-	-	-	-	-	-	-	1	([1])	([1])	-	-	-
Maryland	1	([1])	([1])	-	-	-	-	-	-	-	-	-	3	([1])	([1])	-	-	-	1	([1])	([1])
Massachusetts	13	([1])	([1])	-	-	-	-	-	-	-	-	-	2	2	152	-	-	-	-	-	-
Michigan	13	([1])	([1])	-	-	-	-	-	-	3	4	64	4	8	54	-	-	-	-	-	-
Minnesota	16	20	3,264	-	-	-	-	-	-	5	16	1,740	-	-	-	-	-	-	-	-	-
Mississippi	-	-	-	-	-	-	-	-	-	-	-	-	1	([1])	([1])	-	-	-	-	-	-
Missouri	1	2	253	-	-	-	4	([1])	([1])	4	5	51	1	2	36	-	-	-	-	-	-
Montana	-	-	-	-	-	-	2	([1])	([1])	-	-	-	1	([1])	([1])	-	-	-	-	-	-
Nebraska	-	-	-	-	-	-	-	-	-	3	13	68	-	-	-	-	-	-	-	-	-
Nevada	-	-	-	-	-	-	1	([1])	([1])	-	-	-	3	([1])	([1])	-	-	-	-	-	-
New Hampshire	3	([1])	([1])	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
New Jersey	-	-	-	-	-	-	-	-	-	-	-	-	1	([1])	([1])	-	-	-	1	([1])	([1])
New Mexico	1	([1])	([1])	1	([1])	([1])	1	([1])	([1])	1	([2])	([2])	5	([2])	2	-	-	-	3	([1])	([1])
New York	4	18	358	-	-	-	-	-	-	1	([1])	([1])	10	43	1,502	11	10	475	-	-	-
North Carolina	9	32	2,053	-	-	-	1	([1])	([1])	-	-	-	-	-	-	2	([1])	([1])	-	-	-
North Dakota	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ohio	-	-	-	-	-	-	-	-	-	2	([1])	([1])	16	143	5,141	-	-	-	-	-	-
Oklahoma	9	7	687	-	-	-	-	-	-	5	3	44	-	-	-	-	-	-	-	-	-
Oregon	-	-	-	3	([1])	([1])	-	-	-	-	-	-	-	-	-	-	-	-	2	([1])	([1])
Pennsylvania	6	([1])	([1])	5	([1])	([1])	-	-	-	-	-	-	33	64	1,031	9	52	3,835	3	10	54
Rhode Island	2	([1])	([1])	-	-	-	-	-	-	1	([1])	([1])	-	-	-	-	-	-	-	-	-
South Carolina	4	15	632	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
South Dakota	6	24	4,066	-	-	-	-	-	-	1	([1])	([1])	3	([1])	([1])	-	-	-	-	-	-
Tennessee	-	-	-	-	-	-	9	13	1,375	-	-	-	8	19	496	-	-	-	-	-	-
Texas	3	([1])	([1])	-	-	-	-	-	-	4	25	440	2	([1])	([1])	-	-	-	-	-	-
Utah	-	-	-	-	-	-	1	([1])	([1])	2	([1])	([1])	7	2	57	1	1	43	-	-	-
Vermont	10	([1])	([1])	-	-	-	5	([1])	([1])	-	-	-	-	-	-	21	39	2,637	-	-	-
Virginia	-	-	-	2	([1])	([1])	-	-	-	1	([1])	([1])	3	([1])	([1])	2	([1])	([1])	2	([1])	([1])
Washington	-	-	-	4	18	$45	3	([1])	([1])	1	([2])	1	5	([1])	([1])	-	-	-	3	([2])	4
West Virginia	-	-	-	-	-	-	-	-	-	-	-	-	2	([1])	([1])	-	-	-	-	-	-
Wisconsin	12	10	2,019	-	-	-	-	-	-	30	106	2,065	9	3	49	-	-	-	-	-	-
Wyoming	-	-	-	-	-	-	-	-	-	1	([1])	([1])	4	1	19	-	-	-	1	([1])	([1])
Undistributed	[3](39)	296	14,525	(11)	19	650	(21)	68	12,908	(12)	75	1,027	(36)	58	972	(5)	62	2,147	(10)	34	2,495
Total	158	626	33,847	15	37	695	36	83	14,419	102	728	18,270	191	405	10,103	49	166	9,173	39	282	3,307

[1]Included in "Undistributed." [2]Less than ½ unit. [3]Figures in parentheses not included in total.

Trade

Dimension stone is imported in large quantity, particularly from Europe, Mexico, and Canada. Most of the imports consist of decorative types not widely produced in the United States such as black granite, travertine, onyx, and marbles in different colors, and breccias (table 13). Exports of building and monumental stone are less than one-fifth the value of imports (table 14). Some of the imports are rough or semifinished stone, which subsequently are given finish processing at U.S. plants for domestic consumers. Marble, breccia, onyx, and travertine represent more than one-half of the imports, with granite and slate accounting for most of the balance. Exports are also mostly marble, with granite, limestone, sandstone, and basalt-type precision plates comprising most of the remainder. Some of the imports are transshipped stone produced in one country and finished or semifinished in another country. Examples would be Swedish granite fabricated in a West German mill and marble from several countries passing through Spain or Portugal. Such imports are reported under the nation shipping to the United States rather than by country of primary origin.

TABLE 13. - U.S. imports of dimension stone, for consumption, by classes

Class	1964		1965		1966	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
Granite:						
Monumental, paving, and building stone:						
Rough.................cubic feet	144,907	$656	166,192	$791	150,647	$818
Dressed, manufactured..........do	155,273	1,615	101,242	1,265	134,409	1,156
Other, n.s.p.f....................	-	33	-	63	-	73
Total..........................	-	2,303	-	2,119	-	2,047
Marble, breccia, and onyx:						
In block, rough or squared.................cubic feet	104,137	814	68,300	564	49,043	370
Sawed or dressed more than 2 inches thick.................do	10,371	145	10,383	82	5,349	32
Slabs and paving tiles superficial feet	7,475,465	6,532	7,173,148	6,450	8,402,099	6,541
All other manufactures............	-	4,709	-	4,417	-	4,062
Total..........................	-	12,200	-	11,513	-	11,005
Travertine stone:						
Rough, unmanufactured....cubic feet	112,019	391	62,214	202	58,600	163
Dressed, suitable for monumental, paving, and building stone..................short tons	32,750	1,238	30,926	1,149	31,575	1,338
Other, n.s.p.f....................	-	259	-	158	-	112
Total..........................	-	1,888	-	1,509	-	1,613
Limestone:						
Monumental, paving, and building stone:						
Rough.................cubic feet	1,076	2	900	3	800	1
Dressed, manufactured..short tons	2,788	112	1,560	32	3,190	69
Other, n.s.p.f....................	-	51	-	34	-	53
Total..........................	-	165	-	69	-	123
Slate:						
Roofing................square feet	-	-	5,167	1	5,166	1
Other, n.s.p.f....................	-	1,401	-	1,319	-	1,478
Total..........................	-	1,401	-	1,320	-	1,479

TABLE 13. - U.S. imports of dimension stone, for consumption, by classes-Continued

Class	1964 Quantity	1964 Value (thousands)	1965 Quantity	1965 Value (thousands)	1966 Quantity	1966 Value (thousands)
Stone and articles of stone, n.s.p.f:						
Statuary and sculptures...........	-	$360	-	$411	-	$363
Stone, unmanufactured....short tons	353	14	13,099	21	3,760	75
Building stone, rough....cubic feet	505	1	4,574	6	6,384	11
Building stone, dressed..short tons	100,425	2,029	1,029	39	40	3
Other............................	-	134	-	127	-	28
Total............................	-	2,538	-	604	-	480
Grand total......................	-	20,495	-	17,134	-	16,747

TABLE 14. - U.S. exports of dimension stone, value only
(Thousand dollars)

Year	Building and monumental stone	Slate	Other	Total
1964..........	[1]$2,027	[2]$61	$677	$2,765
1965..........	1,259	[2]76	1,480	2,815
1966..........	1,104	[2]64	1,432	2,600

[1]Includes some dolomite, not classified separately in 1964.
[2]Includes sculpings.

Much imported stone is retained as stock for indefinite periods of time by domestic producers or dealers. Literally hundreds of stones from dozens of countries are kept as yard stock. For very large orders, however, foreign stone would still have to be ordered directly or through a domestic supplier from its point of origin.

The leading countries of origin for U.S. imports of stone are Italy, Portugal, and Canada. Type and tariff class of origin are listed as follows:

Granite, monumental, paving or building, not pitched, lined, etc.:

Canada
Brazil
Sweden
Norway

Granite, monumental, paving or building, pitched, lined, hewn, etc.:

Italy
Canada
Finland

Granite and articles of granite, n.s.p.f., not decorated:

Italy
United Kingdom
Japan
Canada

Granite and articles of granite, n.s.p.f., decorated:

Japan
Italy
Sweden

Limestone, monumental, paving or building, not hewn, sawed, dressed, etc:

Italy

Limestone, monumental, paving, hewn, sawed, dressed, etc.:

Canada

Marble or breccia, in block or rough or squared only:

Italy
France
Portugal

Onyx in block, rough, or squared only:

Mexico
Italy

Marble, breccia, or onyx, sawed or dressed more than 2 inches thick:

Italy
Portugal

Marble, breccia, and onyx slabs not rubbed and not polished:

Italy
Greece
Portugal
Mexico

Marble, breccia, and onyx slabs, rubbed or polished:

Italy
Portugal
Mexico

Marble, breccia, and onyx articles, n.e.s.:

Italy
Portugal
Mexico

Roofing slate:

France

Slate and articles of slate, n.s.p.f., except roofing:

Italy
Portugal

Travertine, not hewn, dressed, sawed, polished, or manufactured:

Italy

Travertine, hewn, sawed, etc., as monumental, paving, or building stone:

Italy

Travertine articles, n.s.p.f., not decorated:

Italy

Travertine articles, n.s.p.f., decorated:

Italy

Stone, n.e.s., suitable for monumental, paving, or building stone, unhewn, unsawed, etc.:

Mexico

Stone, n.e.s., suitable for monumental, paving, or building stone, hewn, dressed, etc.:

French West Indies

The leading countries of destination for U.S. dimension stone exports are Canada and Mexico.

Further discussion of trade classifications and tariffs can be found in the chapter on tariffs and depletion allowances.

Consumption

Consumption trends in dimension stone must be considered from two viewpoints: By demand for each kind of stone and by demand for use such as building, monumental, and flagging.

By kind of stone, proportion of dimension stone sold by tonnage has been relatively constant. In 1950 and 1964 proportions sold, in percent, were as follows:

	Percent		Percent
1950:		1964:	
Limestone......	42	Granite........	35
Granite........	32	Limestone......	32.5
Sandstone......	13	Sandstone......	17.5
Marble.........	5	Miscellaneous..	7.5
Miscellaneous..	5	Marble.........	5
Basalt.........	3	Basalt.........	2.5

Limestone, of course, has been relatively heaviest hit by competition from concrete building, since texture and color are similar. Actual tonnage used, however, has declined only slightly from 1950 (808 tons) to 1964 (779 tons) in an expanding building market. By end use for the same period market share, in percent, has changed as follows:

1950:	Percent	1964:	Percent
Building.......	79.8	Building.......	75.8
Monumental.....	13	Monumental.....	9
Curbing........	4	Flagging.......	8
Flagging.......	3	Curbing........	7
Paving.........	.2	Paving.........	.2

The building stone tonnage decline reflects trends toward thinner facings veneers. Tonnage for building purposes decreased only from 244,000 to 241,000 tons but average values for building purposes (excluding slate) increased from \$24.82 to \$32.36 per ton during the same 14-year period. To some extent this reflects increased finishing costs caused by more sawing per ton of finished veneer slab. Similarly, dimension slate prices during the same period increased from \$20.75 per square foot of roofing slate and \$0.67 per square foot of millstock to \$25.32 per square foot and \$0.96 per square foot, respectively, while quantities changed from 198,000 squares and 3,181,000 square feet to 88,000 squares and 4,112,000 square feet.

Continuation of these consumption trends may be anticipated.

Stocks

The Bureau of Mines does not publish data on producer or dealer stocks. Such stocks, however, are considerable. For marble alone, in 1965, a total of 158 domestic and 183 foreign varieties were listed as stock items. A proportion of these were, of course, specialty items stocked only in small quantities for decorative uses.

CHAPTER 15.--STRUCTURE OF THE INDUSTRY

Producers

The modern dimension stone producer industry is basically divided into two types of operator. The large producer with a more or less complete range of products and one or more quarries and the small producer with only one product or very few products and one quarry. In 1964, there were more than 600 quarries reporting production of dimension stone throughout the United States. These were operated by approximately 40 large firms and about 400 smaller, in part intermittant, operators. Many of the latter firms produced only one, relatively small-size product such as sandstone flagging, rubble, ashlar, or a few gravestones. In 1964 the number of operations reported, by type of dimension stone, were as follows:

Sandstone (including quartzite)............	207
Granite..................................	161
Limestone................................	116
Slate....................................	47
Miscellaneous............................	47
Marble...................................	40
Basalt-type..............................	6
Total..................................	[1]624

[1]Since some small operators may report only intermittently or not at all, the actual figure was probably about 650.

The exact number of firms engaged in domestic production of each stone type can only be closely estimated because some are unidentified subsidiaries and affiliates and some (smaller ones) do not report production regularly. In 1964 approximate number of producer firms, by stone type, were as follows:

Granite..................................	130
Sandstone (including quartzite)............	85
Limestone................................	80
Slate....................................	45
Miscellaneous............................	45
Marble...................................	30
Basalt-type..............................	6
Estimated total........................	421

Of these firms, the 40 most substantial reported production, by type, as follows:

Marble...................................	13
Granite..................................	9
Limestone................................	7
Sandstone or quartzite...................	6
Slate....................................	2
Miscellaneous............................	1
Marble, limestone, quartzite, and miscellaneous stone......................	1
Marble, granite, and limestone............	1
Total..................................	40

The numerous small firms are relatively poorly equipped and range from those with only hand tools to pry loose flagstones to those which may have the minimum necessary mechanical equipment to fabricate small monuments. The larger companies have all been primarily stone producers. The larger firms such as Georgia Marble Co., Rock of Ages Corp., Vermont Marble Co., and Indiana Limestone Co., Inc., have complete technical staffs including engineers and architectural advisors to control not only quarrying and finishing operations but also to perform marketing services such as giving advice to architects and other potential customers. Because stone firms compete not only with each others products but also with alternate structural materials, the major producers maintain elaborate factory-style finishing mills

representing large capital investments. Competition requires close product quality control for assured customer satisfaction and a large-scale efficient operation to obtain a viable profit margin at a competitive product price. Marketing and advertising functions must be well organized and the firm must have the capability to deliver stone of various types, finishes, and dimensions to given specifications on close schedule. Thus a long-established quarry with built-up yard stocks has an advantage over a new producer. Today there are many less quarries and firms than 50 years ago, as large operating capital reserves as well as substantial initial investment are needed to support competitive-scale operations.

Importers

In addition to domestic stone, the industry handles much imported stone both rough and finished. As one might expect the largest domestic stone producers are also among the largest stone importers. In addition there are a few firms importing much foreign stone without domestic sources of their own (although they may also wholesale some domestic stone as well). In general, imported stones consist of varieties, colors, or textures not widely quarried in the United States. Among such are Mexican onyx; European brightly colored marbles in colors and European breccias; travertines; black,red, and green granites; and brightly colored slates.

Processors

In 1963, the Census of Manufacturers of the U.S. Bureau of the Census gathered details on the cut stone industry. The census included establishments primarily engaged in cutting, shaping, and finishing dimension stone but excluded plants buying or selling partly finished monuments or tombstones, thus avoiding persons who rehandle stone from the primary cutters. A total of 857 companies operating 893 plants responded compared with 961 companies operating 977 plants in 1954. Again these figures include stone producers with cutting and finishing operations. Of the 857 companies, only 211 were large enough to employ 20 or more persons and only 36 of these employed 100 or more. Geographically, 153 of the plants were in New England; 163, Middle Atlantic; 178, East North Central; 78, West North Central; 227, South; and 94, West (48 were in California).

Seven-hundred and seventy-five plants dressed stone only, the other 118 also operated quarries in conjunction. The difference between these 118 plants and the Bureau of Mines count of approximately 600 stone-producing establishments should yield the approximate number of quarries without plants selling only flagging, rubble, or other stone in uncut form. Of the total stone handled by those canvassed in 1963 by the Bureau of Census, a breakdown by stone tonnage finished at the quarry site versus stone finished other than at a quarry site showed:

	Manufactured at quarry, percent	Not manufactured at quarry, percent
Granite:		
Building............................	48	52
Monumental..........................	21	79
Other, such as curbing, etc.........	70	30
Limestone:		
Building............................	62	38
Other, such as flagging, etc........	82	18
Marble:		
Building............................	45	55
Other...............................	38	62
Other stone.........................	52	48

Of course some of the stone finished away from quarry sites was manufactured by firms operating quarries at other locales. Nonetheless, there is a clear pattern of granite and marble monument manufacture being in the hands of nonproducers of stone compared with other stone products.

On a percentage basis about 37.5 percent of dimension stone, by value, was finished "at the quarry." Allowing for firms who operate quarries but finish stone at other sites probably about 40 percent by value of all cut stone is at least manufactured in part (certain stages) by nonproducer firms.

Marketing

Dimension stone markets may be local, national, or international, depending upon the type of product, the uniqueness of the stone, and current fashion. Stone from a long-established quarry has a distinct marketing advantage because its qualifications are well known. Architects and engineers will favor this type of stone because its merits require no trial to be proven. If one can look at a building and see a stone that has not appreciably deteriorated over 75- or 100-year use, it is a great comfort to the purchaser and an unbeatable commercial for the vendor.

Marketing is complex because of the various types of companies active in the stone trade as already noted. These are as follows: (1) The manufacturing producer with quarries, mills, shops, and a fully integrated operation; (2) producers with quarries but no mills or shops who sell to wholesalers or manufacturers; (3) wholesalers who buy and sell blocks or slabs of unfinished or semifinished stone; (4) manufacturers who do not own quarries but finish purchased stone; and (5) dealers or contractors who have neither quarries nor mills but who sell finished stone. In addition to competition between companies whose activity levels overlap, there is competition between varieties of stone which have the same function. There are numerous trade organizations organized along various lines reflecting this complexity. They may be based upon type of company, variety of stone produced, or type of product, or even location where stone is produced. They establish ethical standards for their

membership and serve to publicize their member's products. Examples of these institutes and associations are:

Building Stone Institute
420 Lexington Avenue
New York, N.Y. 10017

Allied Stone Industries
Route 3, Box 143
Russellville, Ala. 35653

The Marble Institute of America, Inc.
425 - 13th Street, N.W.
Washington, D.C. 20004

Indiana Limestone Institute of America, Inc.
431 South College Avenue
Bloomington, Ind. 47401

Elberton Granite Association, Inc.
P.O. Box 640
Elberton, Ga. 30635

Pennsylvania Slate Producers Guild, Inc.
120 Hillview Avenue
State College, Pa. 16801

These groups, along with organizations, such as associations of monument builders, are important sources of information and advise to prospective buyers or other interested parties. A typical code of ethics is that of the Building Stone Institute: "We pledge ourselves to maintain the highest possible standards of business and craftsmanship; to give freely of our time and knowledge to architects, engineers, builders, contractors, and the public whenever information and help are needed concerning the use, availability, installation, cost or delivery of natural building stone."

Consumers

From previous sections of this report, it should be apparent that stone consumption is directly related to the number of users--building stone for the living and memorial stone for the dead. Thus, although stone is sold and used everywhere, the large metropolitan areas constitute the major consuming centers. Some stone products, such as roofing slate, became increasingly less competitive with alternate materials as distance from the quarry increased. But even the adverse affect of freight rates can be modified to some extent by forceful or imaginative selling. Most stone products are luxury items, whether the producer cares to stress it or not, and when a consumer wants prestige and appearance, price is secondary.

All of us, every day, in some way, are served by dimension stone. To repeat these many functions of stone here is not necessary, since they are listed in Chapter 4 pertaining to use.

The major direct consumers are builders and architects for building stone, highway engineers for curbing, and monument dealers for memorial stone. Specialized stones are of course outside this pattern; for example, precision plates are sold to precision instrument manufacturers and electrical slate, to producers of electrical equipment.

For products such as the latter two, the number of primary consumers is very small. For the common stone products, literally thousands of primary consumers exist ranging from large construction firms to retail gravestone outlets and even to individuals. A comparison of Bureau of Mines and Bureau of the Census consumption patterns for dimension stone in 1963 is of interest. All figures are based on a breakdown of stone by value. Patterns by variety are presented in table 15; by end use, in table 16; and end use by variety, in table 17.

TABLE 15. - Stone sold or used, by variety
(Percent of total value)[1]

Variety	Bureau of Mines	Bureau of the Census
Limestone	18.8	15.2
Granite	34.0	46.0
Marble	21.8	
Sandstone and quartzite	11.9	
Slate	8.4	33.3
Miscellaneous stone	4.4	
Basalt type	.7	
Not specified	-	5.5

[1]Differences are probably due to greater value added to manufacture of granite and marble monuments, lowering the share of market value accorded to limestone in census figures.

TABLE 16. - Stone sold or used, by end use
(Percent of total value)[1]

Variety	Bureau of Mines	Bureau of the Census
Building	66.6	40.5
Monumental	25.0	35.0
Paving	.1	
Curbing	4.2	12.4
Flagging and other	4.1	
Not specified	-	12.1

[1]Discrepancy is probably due to higher value added for monuments in census figures, and roofing and millstock slate added in "building" by the Bureau of Mines and placed in "other" by the Bureau of the Census.

TABLE 17. - Stone end-use patterns, by variety
(Percent of total value)

Variety	Bureau of Mines	Bureau of the Census
LIMESTONE		
Building	99.2	88.1
Other	.8	3.6
Not specified	-	8.3
GRANITE		
Building	36.7	32.6
Monumental	51.0	55.0
Other	12.3	6.1
Not specified	-	6.3
MARBLE		
Building	65.0	52.0
Monumental	35.0	42.0
Other	-	-
Not specified	-	-
SANDSTONE AND QUARTZITE		
Building	87.3	-
Flagging	12.0	NA
Curbing	.7	-
SLATE		
Building (roofing)	24.4	-
Flagging	20.3	-
Millstock	47.5	NA
Miscellaneous stone	7.8	-
MISCELLANEOUS STONE		
Building	97.0	NA
Flagging	3.0	-
BASALT		
Building	NA	NA
Other	NA	NA

CHAPTER 16.--EMPLOYMENT, COSTS, PRODUCTIVITY, AND PRICES

The 1963 Census of Manufacturers is the most recent source of detailed employment cost and productivity data for the dimension stone industry. The industry reported a total payroll of $85,745,000 for 18,340 employees. Production workers received $66,657,000 of this, paid to 15,259 persons working 30,896,000 man-hours. Thus each of these production workers was paid an average of $4,368.37 per year or $2.16 per hour. Productivity can be measured only against value of stone shipped because quantities shipped were not obtained in this census. The total value of stone shipped, according to census data,was $217,176,000 or $7.03 per production-worker hour.

Measured costs contributing to the value of stone shipped can be accounted for as follows:

	Amount
Value of stone shipped	$217,176,000
Costs:	
Cost of materials	86,633,000
Payroll	85,745,000
Capital expenditures	6,693,000
Total of major costs	179,071,000

The average balance after operating costs per reporting company graphically illustrates the small average size of the 857 reporting firms and also the small profit margin which necessitates automation and new, more efficient production or handling equipment as the only real hopes for any price decreases. However, the low profit realization and small size of most operations make such improvements hard to pay for, or to even justify for the smaller operators.

New production equipment and methods have gradually transferred many stone industry jobs from the highly skilled craftsman category to essentially that of machinery operator. This holds true for quarrying as well as finishing operations. In the quarry, equipment such as the jet-channel rig require less training than some earlier methods. Shop equipment, notably grinding and polishing machines are becoming increasingly automated. Of course, the smaller operators, such as family-style firms with less modern facilities require more craftsmanship. As older members of these companies retire, it is anticipated that some will go out of business or merge with larger, better capitalized firms.

The one task in the stone industry that remains an art or craft is sculpting and hand lettering. To keep these positions staffed as the older craftsmen retire, firms are turning more and more to true sculptors, including graduates of art schools. Some of the latter, of course, carve memorials as a means of earning their bread while following their artistic avocation in their free time.

The Bureau of Mines annually canvasses dimension stone firms which operate quarries to obtain data for statistical analysis of accidents. In 1963, a total of 672 quarries and 313 mills responded to the survey. Quarries employed 4,724 persons and mills 6,678 persons for a stone-producing industry-wide total of 11,402 persons who worked 22,013,248 man-hours. A breakdown of employees by type of stone is given in table 18. In 1963, a total of 2,616,000 tons of dimension stone were sold or, 0.12 ton per man-hour. The historical series of figures reported to the Bureau of Mines show only a slight employment decline over the years. In 1960, 12,756 men worked 24,740,021 man-hours to produce 2,257,000 tons of dimension stone (0.09 ton per man-hour) and in 1940, 12,156 men worked 20,952,655 man-hours to produce 2,261,180 tons (0.11 ton per man-hour). The tonnage per man-hour has exhibited no significant productivity change. However, since product character has changed so

greatly since 1940, perhaps a more valid criterion would be in terms of dollars worth of stone produced per man-hour.

Year	Value per man-hour in dollars	Value in constant 1940 dollars
1940..............	$1.19	$1.19
1960..............	3.48	1.34
1963..............	4.38	1.52

TABLE 18. - Employment in dimension stone industry in 1963, by type of stone

Type of stone	Employed in quarries	Employed in mills	Total employees	Percent of total dimension stone employees
Granite.............	1,389	2,556	3,945	34.6
Limestone...........	993	1,045	2,038	17.9
Marble..............	741	1,381	2,122	18.6
Sandstone...........	947	784	1,731	15.2
Slate...............	431	599	1,030	9.0
Traprock............	25	26	51	.4
Miscellaneous.......	198	287	485	4.3
Total...........	4,724	6,678	11,402	100.0

Source: Bureau of the Census.

Value per man-hour in 1963 is of course lower than the $7.03 derived from the Census Bureau compilation because of a higher proportion of finished stone in the census figures.

F.o.b. quarry or plant values of dimension stone are reported annually to the Bureau of Mines by producers. Average values reported to the Bureau for 1966 are given in table 19.

The figures in table 19 are not retail prices which include transportation, handling, dealer profits, and overhead. Actually most stone today is used in thin slab, and prices are quoted in square feet of surface not per cubic foot or per ton. Depending on type of stone, finish, size of order, distance from quarry or plant, and other factors, actual sale prices present a bewildering array and can best be determined by obtaining specific quotations from producer or supplier firms. Selling prices, f.o.b. finishing plants may range from $0.40 to $25.00 per square foot.

Prices, of course, cover a wide range due to type of stone, variety, finish, size of slab, and so forth. Prices would be lower for certain ashlar veneers and higher for polished panels of highly decorative, unusual stones. To these f.o.b. prices, the port of entry prices for imported stone, transportation costs must be added which may add from 10 to 50 percent to the delivered price of the stone. Subsequent erection or installation costs generally may range from $0.40 to $2.00 or more per square foot. Again, such costs depend upon what is being installed, location, method of installation, and size of stone units.

TABLE 19. - Average value of stone, by type in 1966, f.o.b. quarry or plant

	Per ton	Per cubic foot
Granite:		
Building stone:		
Rough construction	$11.60	-
Rough architectural	48.00	$4.10
Dressed construction	72.60	5.80
Dressed architectural	131.00	10.80
Rubble	4.60	-
Monumental stone:		
Rough	52.40	4.20
Dressed	192.00	15.90
Paving blocks	31.60	-
Curbing and flagging	29.80	2.50
Average total granite	54.00	-
Basalt and related stones, total	18.80	-
Marble:		
Building stone:		
Rough architectural	43.60	3.70
Dressed-sawed	96.70	8.50
Dressed-cut	282.00	24.00
Monumental stone	213.00	18.10
Average total marble	174.00	-
Limestone:		
Building stone:		
Rough construction	6.40	-
Rough architectural	17.10	1.20
Dressed-sawed	29.40	2.20
Dressed-cut	89.90	6.80
Rubble	5.10	-
Curbing and flagging	7.00	.50
Average total limestone	25.00	-
Sandstone:		
Building stone:		
Rough construction	15.80	-
Rough architectural	19.70	1.50
Dressed-sawed	36.40	2.70
Dressed-cut	37.40	2.90
Rubble	4.00	-
Curbing	48.00	3.20
Flagging	28.00	2.30
Average total sandstone	25.00	-
Miscellaneous stone:		
Building-sawed	52.90	4.50
Building-rubble	2.30	-
Flagging	19.40	1.70
Average total miscellaneous stone	11.80	-

TABLE 19. - Average value of stone, by type in 1966, f.o.b. quarry or plant--Continued

	Per ton	Per cubic foot
Slate:		
Roofing....................................	$97.80	[1]$14.30
Millstock..................................	-	-
Electrical, structural and sanitary............	124.00	[2]1.10
Blackboards and bulletin boards................	329.00	[2].90
Billiard tabletops...........................	140.00	[2]1.20
Flagstones.................................	24.80	[2].10
Miscellaneous..............................	32.70	-
Average total slate.........................	55.00	-

[1]Per square.

[2]Per square foot.

The cost advantage claimed for stone is in maintenance. No one really claims that stone is the most economical material based on initial cost. But stone never requires painting like wood or steel, rarely cracks or crumbles like concrete, and requires cleaning far less frequently than glass. Thus it is that stone proves its worth over the life span of a building.

CHAPTER 17.--TARIFFS AND DEPLETION ALLOWANCES

Tariff rates established by the Tariff Act of 1930 have been subjected to much modification and reduction. Applicable rates are much lower at present because of trade agreements with individual countries and concessions made under the General Agreement on Tariffs and Trade (GATT). The original tariff rates, however, still apply to imports from Communist countries or those "under Communist domination or control." Complete tariff schedules are set forth in Tariff Schedules of the United States Annotated (1968), United States Tariff Commission, TC Publication 222. Under this tariff schedule, dimension stone imports are classified under the following items (shown with TSUS number):

513.51 Stone statuary and sculptures not specially provided for, the professional productions of sculptors only.

Granite, suitable for use as monumental, paving, or building stone:

513.71 Not pitched, not lined, not pointed, not hewn, not sawed, not dressed, not polished, and not otherwise manufactured.

513.74 Pitched, lined, pointed, hewn, sawed, dressed, polished, or otherwise manufactured.

Other not specially provided for:

513.81 Not decorated.

513.84 Decorated.

Limestone and articles of limestone, suitable for use as monumental, paving, or building stone:

514.21 Not hewn, not sawed, not dressed, not polished, and not otherwise manufactured.

514.24 Hewn, sawed, dressed, polished, or otherwise manufactured.

Other not specially provided for:

514.41 Not decorated.

514.44 Decorated.

Marble, breccia, and onyx, and articles of one or more of these substances:

514.51 Marble, breccia, in block, rough or squared only.

514.57 Marble, breccia, or onyx, sawed or dressed, over 2 inches thick.

Slabs:

514.61 Not rubbed and not polished in whole or in part.

514.65 Rubbed or polished in whole or in part.

514.81 Other, not specially provided for.

514.91 Quartzite, whether or not manufactured.

Slate and articles of slate:

515.11 Roofing slate.

515.14 Other slate, not specially provided for.

Travertine and articles of travertine:

515.21 Travertine, not hewn, not sawed, not dressed, not polished, and not otherwise manufactured.

515.24 Travertine, hewn, sawed, dressed, polished, or otherwise manufactured, and suitable for use as monumental, paving, or building stone.

Others not specifically provided for:

515.31 Not decorated.

515.34 Decorated.

Stone and articles not specially provided for, suitable for use as monumental, paving, or building stone:

515.51 Not hewn, not sawed, not dressed, not polished and otherwise not manufactured.

515.54 Hewn, sawed, dressed, polished, or otherwise manufactured.

Other:

515.61 Not decorated.

515.64 Decorated.

Applicable and statutory rates for these items, with the GATT rate prior to January 1, 1968, are set forth in table 20.

TABLE 20. - Tariff schedules of the United States, for dimension stone[1]

Item	Unit	Prior rate	Rate of duty[2] effective with respect to articles entered on or after January 1					Statutory rate[3]
			1968	1969	1970	1971	1972	
513.51	-	8%	7%	6%	5.5%	4.5%	4%	20%
513.71	Cubic feet	1¢	Free	Free	Free	Free	Free	25¢
513.74	....do....	12.5%	11%	10%	8.5%	7%	6%	60%
513.81	-	15%	13%	12%	10%	9%	7.5%	60%
513.84	-	27%	24%	21.5%	18.5%	16%	13.5%	40%
514.21	Cubic feet	2¢	1¢	1¢	1¢	1¢	1¢	15¢
514.34	-	10%	9%	8%	7%	6%	5%	25%
514.41	-	15%	13%	12%	10%	9%	7.5%	30%
514.44	-	27%	24%	21.5%	18.5%	16%	13.5%	40%
514.51	Cubic feet	27.5¢	24¢	22¢	19¢	16¢	13.5¢	65¢
514.54	....do....	32.5¢	29¢	26¢	22¢	19¢	16¢	65¢
514.57	....do....	50¢	45¢	40¢	35¢	30¢	25¢	$1.00
514.61	Superficial feet	5.5%	4.5%	4%	3.5%	3%	2.5%	13%
514.65	....do....	7%	6%	5.5%	4.5%	4%	3.5%	15%
514.81	-	21%	18.5%	16.5%	14.5%	12.5%	10.5%	50%
514.91	Tons[4]	Free	Free	Free	Free	Free	Free	Free
515.11	Square feet	25%	22%	20%	17%	15%	12.5%	25%
515.14	-	10.5%	9%	8%	7%	6%	5%	25%
515.21	Cubic feet	10.5¢	9¢	8¢	7¢	6¢	5¢	25¢
515.24	Short tons[5]	21%	18.5%	16.5%	14.5%	12.5%	10.5%	50%
515.31	-	15%	13%	12%	10%	9%	7.5%	30%
515.34	-	27%	24%	21.5%	18.5%	16%	13.5%	40%
515.51	Cubic feet	2¢	1.5¢	1¢	1¢	1¢	1¢	15¢
515.54	Short tons[5]	21%	18.5%	16.5%	14.5%	12.5%	10.5%	50%
515.61	-	15%	13%	12%	10%	9%	7.5%	30%
515.64	-	27%	24%	21.5%	18.5%	16%	13.5%	40%

[1]Rates given in percent are "ad valorem;" those expressed in cents are per the unit expressed in the "Unit" column of the table as adapted from Tariff Schedules of the United States.

[2]By Presidential Proclamation, established under the General Agreement on Tariff and Trade (GATT), Kennedy Round, Geneva, Switzerland, 1967.

[3]Applicable rate applied to imports from Communist countries or those designated as under "Communist domination or control."

[4]2,240 pounds.

[5]2,000 pounds.

Percentage depletion allowances, on both foreign (U.S.-owned) and domestic properties taxed by the United States, are uniform for all dimension and ornamental stone. Allowances are 15 percent, except 5 percent when used for riprap, ballast, road material, rubble, concrete aggregate, or similar purposes. Depletion-allowance tax laws are complex, and computations can be made in various ways and are affected by interpretation of definitions and

special rules. Administrative simplifications and tax advantages can be gained by following the best computation procedure for a given property or group of properties. The allowances aid the owners of wasting (nonrenewable) assets by recognizing that such owners incur costs in searching for new deposits (efforts which may result in expensive failures) and because production from a property results in wasting of capital assets through depletion of their equity in the existing deposit. An extensive discussion of percentage depletion in all its ramifications, along with other facets of tax law as applied to mineral operations, can be found in the book, "Economics of the Mineral Industries," in the chapter entitled "Taxation of Mineral Properties" by Granville S. Borden. The book was published in New York in 1959 by the AIME.

CHAPTER 18.--RESEARCH

Continuing research by the dimension stone industry and manufacturers of machinery has resulted in many improvements in methods and equipment for extracting and shaping stone. Installed costs have been reduced by the development of thinner veneers, modular units, and precast sections, and a wide variety of surface finishes have been made available. The larger companies conduct research on increasing durability of their products, adaptability of stone for interior and exterior work, and color stability. Associations of memorial stone producers have conducted marketing research programs designed to improve the quality of stone offered to the public and to increase the dependability of dealers. Diamond-set gangsaws, capable of cutting 40 or more sections of veneer stone at once, huge diamond-set circular saws, and diamond-set grinding and honing machines have revitalized stone cutting and polishing. Flame jet channeling and giant wire saws have reduced unit costs and lessened waste in quarrying operations. Research in cutting stone by the use of sound waves or light waves (laser), which may have a similar future impact as flame jet channeling and giant wire saws, is being conducted at the Massachusetts Institute of Technology.

A few educational institutions and industry associations have devoted particular research efforts on problems of utilizing waste products. Many new byproduct uses for such former waste products have been developed (see section on Quarry and Mill Waste Disposal).

The National Bureau of Standards conducts continuing research on the physical and chemical properties of building stone, on the durability and resistance to attack of such stone in various environments, and on the development of test methods by which various stones can be evaluated. Specifications and tests adopted by the American Society for Testing and Materials are based to a large extent on National Bureau of Standards research efforts. Among the industry and building associations prominent in sponsoring institutional research in dimension stone problems are The Building Stone Institute, The Marble Institute of America, the Pennsylvania Slate Producers Guild, The Indiana Limestone Institute of America, and The National Building Granite Quarries Association.

CHAPTER 19.--LEGISLATION, GOVERNMENT PROGRAMS, AND STRATEGIC FACTORS

Almost every nation in the world has deposits of stone suitable for dimension purposes. Most countries, if foreign stone supplies were interrupted, could be self-sufficient, although under normal trade conditions considerable quantities of dimension stone do cross international boundaries. Some varieties of stone have no exact counterparts outside certain countries and, on this account, they are conveyed long distances to satisfy special architectural, monumental, or decorative demands. However, in time of war or similar emergency, nonessential building, including luxury structures and memorials, is curtailed. This reduces the need for dimension stone in general and special luxury stones in particular. With few exceptions, dimension stone deposits are owned and operated by nationals of the respective countries in which they occur. Finishing may be conducted wholly or partly in either the producing or consuming nation by its own nationals.

United States Government legislation affecting dimension stone generally affects all mineral industries and deals with safety, health, and zoning legislation, depletion allowances, protective tariffs, developmental loan programs, Government building programs, and the need for grave stones in national cemeteries or monuments to national heroes.

The depletion allowance for domestic and foreign dimension stone produced by United States firms is 15 percent except if the stone is used for riprap or rubble in which case it is 5 percent. Waste stone (crushed and broken) receives the 5-percent allowance if used for ballast, road material, concrete aggregate or similar purposes. For higher quality (chemical and metallurgical) use such as cement, lime, or filler raw material, the 15-percent rate would apply.

Tariff regulations are discussed in this report in the section on that subject. They are very complex because they involve many varieties of dimension stone, several stages of manufacture for each variety, and from time to time, tariff changes. Rates for stone imported from Communist countries are somewhat higher than those from non-Communist countries.

There are no special developmental loan programs for dimension stone operations. In certain cases, however, dimension stone projects may qualify for assistance under various programs administered by such agencies as the Small Business Administration, Farmers Home Administration in the U.S. Department of Agriculture, or the Economic Development Administration in the U.S. Department of Commerce.

The same national and State mine and quarry safety laws must be observed for working dimension stone as are used for working other mineral commodities. In addition, on public lands open to mining activity, the Bureau of Land Management Lode and Placer Mining Regulations and the specifications of the Mining Claims Occupancy Act apply. Applicable zoning, land use, and air and water pollution control regulations must be observed.

The greatest governmental impact on the dimension stone industry results from Federal, State, and local government use of stone. Since more dimension stone is used in prestige and institutional-type buildings, governments are one of the larger dimension stone consumers. The industry is particularly sensitive when the General Services Administration, the Capitol Architect, or other governmental building planners change specifications. Constant legislative liason must be maintained to stress the beauty and lasting qualities of stone, as compared, for example, with exposed, aggregate precast concrete clad structures. The loss of even one large governmental building or monument contract may be a serious blow to the individual stone producer. Contracts to supply stone grave markers to national and other government cemeteries are another important source of revenue for certain stone producers and provide steady employment to a nucleus of experienced personnel at supplying quarries and plants.

CHAPTER 20.--INDUSTRY OUTLOOK AND PROBLEMS

It appears unlikely that the dimension stone industry, in the near future, will approach the production volume of the pre-World War II era. Three factors limit production: (1) Increasing demand by builders for more efficient structures with greater rental or usable space--obtained by functional design, modular construction units, and elimination of dimension stone as a load-bearing material--and with aesthetic values gained through use of horizontal and vertical lines rather than the heavy columns and monolithic carvings common some years ago; (2) continuing competition from alternate building materials such as glass, metals, ceramic tiles, plastic panels, and precast concrete panels faced with exposed aggregate, colored glass, or mosaic tile; and (3) continuation of the taste trend of part of the population toward memorial parks which prohibit use of monuments and private mausoleums and to smaller monuments in conventional cemeteries, thereby restraining the growth of the monumental stone segment of the industry.

Demand for slate blackboards may increase due to requirements for additional classrooms to accommodate increased numbers of students.

More favorable trends are seen in the growing use of dimension stone panels and veneers as independent units of construction to protect interiors of buildings from the weather and to give attractive exteriors. New efficiencies in cutting thinner stone slabs, combined with the development of insulating panels faced with ornamental stone veneers, should also increase the demand for dimension stone. The increased use of crushed and graded stone for exposed aggregate panels should enable dimension stone quarries to dispose of some waste material at a profit. Improved methods for attaching panels to structures make this sector of the industry more competitive by lowering labor costs. Some increase is expected in demand for modular rubbed or riven slate veneer for curtain walls and interior flagging. This may offer an outlet for some types of slate that split unevenly.

Specifications and standard tests by which durability of stone may be forecast are either unavailable or are not generally accepted as valid. There appears to be no significant correlation between compressive strength

tests and durability, either in surface behavior (architectural appearance) or bulk behavior (engineering use). Present accelerated weathering tests based on resistance to freezing and crystallization tests such as the sodium sulfate soak are unreliable. The standard Los Angeles and Deval tests give insufficient information for rating building stone.

Present methods of producing dimension stone yield a high percentage of waste which can be disposed of only on a highly competitive market after additional processing.

The lack of dimensional standardization increases cost of many building stone units. Costs remain high and broad use of dimension stone is restricted because mechanization of stone processing plants and development of methods for quantity production have lagged.

Lack of uniform terminology causes confusion among producers, builders, and architects.

Spalling, discoloration, and fracturing of some stone after it is in place are continuing sources of concern and tend to lessen confidence in durability of some stones.

The industry lacks complete knowledge of many modern materials that may be used to seal porous stone for protection against weathering and decay.

The principles involved in cleaning stone buildings and the deleterious effects of some techniques now in general use have received insufficient consideration.

Continuing problems are those relating to increasing efficiency of drilling, blasting, sawing, shaping, finishing, and handling stone. The effect of various quarrying and finishing methods on durability is not fully known.

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HORIZONTAL BORING TECHNOLOGY: A STATE-OF-THE-ART STUDY

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

September 1968

Bureau of Mines
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HORIZONTAL BORING TECHNOLOGY: A STATE-OF-THE-ART STUDY

by

James Paone, William E. Bruce, and Roger J. Morrell

ERRATA

Page 11, line 16: Last word should be "splices."

Page 18, table 3, eighth entry: 1,095 in first column should be 1,905, and 147.00 in fifth column should be 147.63.

Page 20, table 6, in column 3, the sixth numerical entry should be 16,000, not 1,600. In column 6, the twelfth through fifteenth numerical entries should be as follows:

$0.80
.92
1.04
2.76

Page 59, table 11: Footnote references should be inserted in the table as follows:

[1]Pertains to "Cost per foot" and "Cost per cubic yard" in column 1.
[2]Pertains to the figure $0.045 in column 2.
[3]Pertains to the figure $0.48 in column 5.

Page 76, second paragraph under "Support of Hole": The last sentence should read as follows:

> The process, called the electrochemical method, in some applications involves the use of a special mixture of clay and binding material and the application of a direct current while in other cases the application of current is all that is required.

HORIZONTAL BORING TECHNOLOGY: A STATE-OF-THE-ART STUDY

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* * * * * * * * * * * information circular 8392

UNITED STATES DEPARTMENT OF THE INTERIOR

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FOREWORD

The White House Conference on Natural Beauty, held in Washington, D. C., May 25, 1965, emphasized the desirability of underground installation of electric utilities and recommended:

> "... a greater endeavor in the field of research and development to the end that systems and equipment be developed for the efficient and economic transmission of electric energy at high voltages underground over long distances..."

The Secretary of the Interior, in managing America's Department of Natural Resources, has a dual concern in this area. It is at once pragmatic and aesthetic. On the practical side lie his responsibilities in the field of power generation, transmission, and marketing. On the aesthetic side lies his concern for the impact of power facilities on the historic, recreational, and scenic environment.

In order to protect and conserve the natural beauty of areas through which power must be transmitted, two significant steps have been taken; first, the encouragement and stimulation of an aggressive research and development program to improve the technology required to place electric power transmission lines underground, and second, the preparation of this report on the state of the art of horizontal boring technology.

Research and development are being accomplished through the Electric Research Council, on which the Department has two representatives--one serving as a member of the Council and the other on the Council's Underground Transmission Task Force.

This state-of-the-art report constitutes the Bureau of Mines' contribution of its expertise on tunneling and machine boring and presents information on the latest devices available for underground boring. It is timely in view of the great activity by the utilities in placing electric power and communication facilities underground. It is also relevant to industrial applications requiring underground excavation without destroying the surface area.

Toward these national objectives, Bureau of Mines programs on rapid disengagement of unconsolidated materials or rock have significant potential for improving the state of the art or providing important developments that will facilitate successful exploitation of the Nation's inner space.

Kenneth Holum
Assistant Secretary
Water and Power Development
U.S. Department of the Interior

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HORIZONTAL BORING TECHNOLOGY: A STATE-OF-THE-ART STUDY

by

James Paone,[1] William E. Bruce,[2] and Roger J. Morrell[2]

ABSTRACT

This report on the state of the art of horizontal boring technology for underground power transmission installations was prepared by the Bureau of Mines at the request of the Department of the Interior.

This paper describes the different machines and methods used in augering, impacting, pushing, drilling, and machine tunneling horizontal holes through soil and rock. A review of the borehole survey and guidance tools and techniques applicable to these methods is also given. Nonboring methods used for emplacement of power distribution and transmission lines are briefly discussed.

The paper ends with a brief technical forecast, an analytical summary of the state of the art, and recommendations based on power industry needs.

Horizontal boring techniques for power distribution lines installation are adequate to meet the requirements of the power industry, particularly where such burial involves relatively short distances in soil or soft rock.

For burying power transmission lines, particularly in the harder rocks and over relatively long distances, horizontal boring methods are not as well advanced. Research and development as well as economic incentives to equipment manufacturers could substantially improve the state of the art.

Obstacle detection and guidance systems for directing boreholes to specified targets need major improvements to meet the requirements of the power industry for underground burial of distribution and transmission lines.

[1]Physical scientist, senior commodity specialist, Bureau of Mines, Washington, D.C.; formerly supervising mining engineer, Twin Cities Mining Research Center, Bureau of Mines, Minneapolis, Minn.

[2]Mining engineer, Twin Cities Mining Research Center, Bureau of Mines, Minneapolis, Minn.

INTRODUCTION

This investigation was made in response to a request on July 21, 1967, by the Assistant Secretary, Water and Power Development, Department of the Interior, to the Bureau of Mines to make a comprehensive review of horizontal-boring technology relating to underground power installations.

The review is concerned primarily with 3- to 36-inch horizontal holes from several hundred to several thousand feet in length. Other factors related to underground power transmission, such as thermal, electrical, or the like, are not considered.

The costs of boring and of conventional installation techniques are compared to provide an economic evaluation of the currently available techniques.

Most of the information in this report was obtained from equipment manufacturers, construction firms, and utility companies.

ACKNOWLEDGMENTS

The prompt assistance and courteous cooperation of personnel of many organizations made this investigation possible. Because the contributors are so numerous, they are acknowledged with appreciation and listed in appendix A.

BACKGROUND

An electric power system consists of three essential functions: generation, transmission, and distribution. The generation component includes the generating station and step-up substation; the transmission component includes the transmission line and stepdown substation at typical voltage levels ranging from 69 to 345 kv for underground lines and 69 to 500 kv for overhead transmission lines; and the distribution component includes the distribution line carrying the commonly used voltages of 120, 208, and 240 volts and the distribution transformer, as well as the line to the service customer.[3]

The Federal Power Commission reports that a total of 1,600 miles of underground transmission lines of 60- to 345-kv capacity are now in service in the United States. Although the 1,600 miles of underground transmission is only a small part of the total 250,000 miles of transmission, its concentration in the metropolitan areas often represents a substantial part of the investment in transmission facilities for such areas.[4] By 1980 it is estimated that approximately 3,000 miles of transmission lines will have to be placed underground.[5] The cost of burying electric transmission lines underground within a radius of 30 miles from the center of each of our most populated cities, will exceed $1.5 billion with the methods now available.

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[3] Underground Power Transmission. A Report to the Federal Power Commission's Advisory Committee on Underground Transmission. April 1966, 187 pp.

[4] Work cited in footnote 3.

[5] U.S. Department of Interior. Program for Advancing Underground Electric Power Transmission Technology. Report to the President. Apr. 27, 1966, 33 pp.

Comparative studies of overhead and underground transmission lines show that overhead installations are considerably cheaper than underground installations. As right-of-way costs for overhead transmission in congested areas increase, the cost difference narrows. The conclusion is that in the future overhead transmission lines could not be permitted to traverse the heart of a city. Improved methods of underground emplacement will certainly reduce the difference in costs and even further favor underground emplacement.

Utility lines are being installed overhead and underground by a variety of methods. Although overhead installation is usually cheaper, an underground system offers such appreciable advantages as making rights-of-way available for other uses, improving public safety, and increasing protection from storms, with consequent greater continuity of service and lower maintenance costs. Completely burying a utility calls for a variety of methods and equipment. One type of equipment may be used for lines traversing open country, and another type for urban areas. River, highway, and railroad crossings require specific tools and techniques. The wide variety of soils and rocks to be penetrated also increases the specialization of equipment needed. Some of the nonboring methods being used to bury utility systems will be described, followed by a state-of-the-art review of boring methods applicable to underground emplacement of electric lines.

NONBORING METHODS

Plowing

Over 75 years ago cities began specifying underground power installations. For more than 30 years underground utility conduits have been placed by plowing methods. Today many utilities in this country and abroad are plowing in millions of feet of lines annually in diameters up to 6-5/8 in or more and to depths of 12 ft or more. Probably the present average depth does not exceed 6 ft; optimum depth usually depends on government codes and company experience. The highest voltage line we are aware of that has been placed underground by plowing carries 69 kv. Plows of greatly varying types with many different features can be used for cross-country plowing or in suburban lawns. Besides conventional blade plows for dryland jobs, there are water-jet-type plows specially designed for river or other water crossings. Some of these water-jet plows are sled types for operating over the bottom of the water course and others have the plowshare extending vertically below the ship or barge through the water and into the bottom soil.[6] In dry land and underwater plowing operations the common practice is to make one or more pilot runs, on land to soften and open the proposed route for easier placement and to detect obstacles and underwater chiefly to detect or locate obstacles.

Plowing may be divided into two main modes of operation: "pulling in" and "feeding in" (the latter is sometimes referred to as "planting").

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[6] Bender, F. J., and J. V. McBride. Two 4,300-Ft. Submarine Cable Sunk 5-ft. Deep in Channel Bottom. Elec. World, v. 162, No. 11, Sept. 14, 1964, pp. 20-21.

Electrical World. Conduits "Hydro-Jet" Embedded for 750-Ft. River Crossing. V. 160, No. 25, Dec. 16, 1963, pp. 58-60.

FIGURE 1. - Crawler-Type Tractors and Plow for Plowing in Cables or Pipes.
(Courtesy, F. B. Ryan Mfg. Co., Inc.)

In the first, "pulling in", the conduit or pipe to be buried is pulled behind the plow tooth as the tool slices through the earth. The tooth or hole-forming mandrel can be changed to accommodate the conduit involved. The most significant feature of "pulling in" is the high drawbar force necessary to drag 1,000 ft or more of 6-in-diam pipe through the soil (table 1).[7] This power is usually supplied by two or more large crawler tractors (fig. 1).

TABLE 1. - Power developed by typical prime movers

Tractor type[1]	Flywheel hp	Pull at 1.5 mph, lb	Pull at stall, lb
D6 Caterpillar...........	93	19,000	27,000
D6B Caterpillar..........	93	21,000	35,000
D6C Caterpillar..........	120	33,000	50,000
D7(17A) Caterpillar.......	112	33,000	50,000
D7E Caterpillar..........	160	50,000	85,000

[1]Reference to specific brands is made for identification only and does not imply endorsement by the Bureau of Mines.

[7]Atwood, John J. Economics of Plowed-In Pipe. Proc. AGA Distribution Conference, St. Louis, Mo., May 1, 1967 (in press).

The second method, "feeding in", involves feeding the conduit to be buried into a so-called "cable shoe" and laying it along the bottom of the slit as the tool moves through the earth. This method, with its related techniques, permits feeding in single or multiple conduits buried at the same depth or at different depths up to a vertical separation of 12 in (figs. 2 and 3). Regardless of the plowing method used the only backfilling of the slice is done by running one track of a tractor over the slice for closure.

In another feeding-in method a hollow rotary-cutter bar studded with replaceable cutting elements is lowered into the ground while it is rotating. The unit then plants the cable fed through the hollow cutter bar to a maximum depth of 4 ft and covers it at rates of up to 75 fpm. Figures 4 and 5 show different views of a typical feeding-in plow capable of handling flexible cable, conduit, or tubing up to a 6-in diameter. Since the cutter bar can be moved laterally, it can be swung to go around obstacles, to plant within 15 in of a wall, or plant cable on a 2-ft radius on corners. A simple positioning device automatically maintains the cutter bar at the specified depth, however irregular the terrain being traversed.

Such feeding-in equipment can be tractor mounted (fig. 6) or trailer mounted (fig. 7). Tractor-mounted units often permit steering the blade to allow laying conduit to left or right of the tractor center line. This flexibility is advantageous where the tractor must operate well off the road but the cable must be laid beside the road, when plowing adjacent to buildings, and when going around obstacles. This offset device makes it possible for the tractor to continue in a straight line since only the blade is shifted.

Another equipment distinction may be based on plowing with or without superimposed vibration. Thus, plows are referred to as either fixed-tooth, which have already been described, or vibrating-tooth plows. The outstanding advantage of the vibratory plows is the low drawbar force requirement. Vibratory plows require only 20 to 50 percent of the drawbar pull required by fixed-tooth units.[8] Vibration in plows is achieved either by a mechanical linkage transmitting oscillations to the plowshare or by vibration induced by an unbalanced weight method in which a vibrator is placed atop the plow. When sonic resonance principles are applied so that the vibration is at the fundamental frequency of the plowshare, slicing is achieved with a minimum energy requirement.[9] Figures 8 and 9 show two different types of vibrating plows. The resonant system thus offers the maximum effect from a given vibration source. One advantage of a resonant system is its ability to store large amounts of energy for release as needed. This property is analogous to that of a flywheel on a jaw crusher or other similar machine. A resonant system is reported to deliver up to several times as much power

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[8] Kemnitz, Louis A., Glen P. Buck, and Lloyd F. Brisk. Vibrating Plows for Direct Burial of Cables, Wires, Tubing. SAE Trans., Paper 660043, 1967, pp. 186-190.

[9] Newfarmer, L. R. Progress of Research on Sonic Methods and Equipment for Underground Utility Installation. IEEE Tech. Conf. on Underground Distribution, Sept. 28, 1966, pp. 379-403.

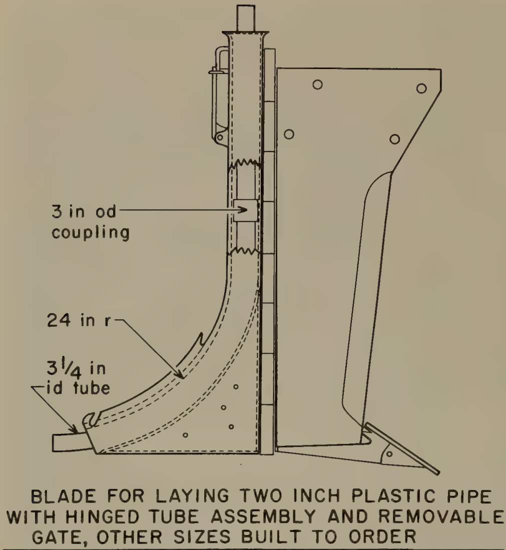

FIGURE 2.-Plowshare for Single-Cable Burial.
(Courtesy, F. B. Ryan Mfg. Co., Inc.)

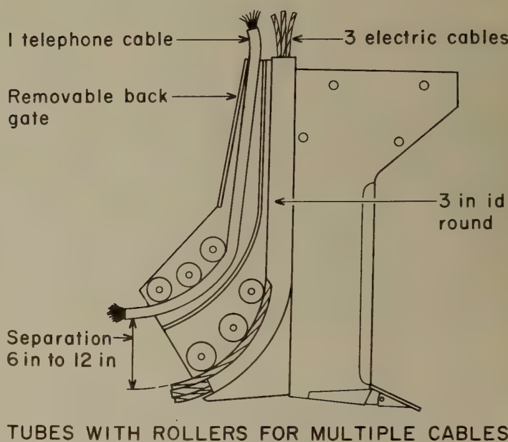

FIGURE 3.-Plowshare for Multiple-Cable Burial.
(Courtesy, F. B. Ryan Mfg. Co., Inc.)

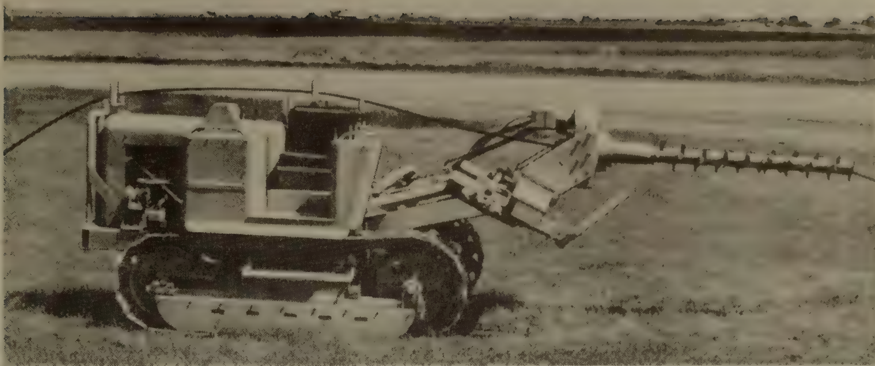

FIGURE 4. - Plow With Hollow Rotary-Cutter Bar. *(Courtesy, Woodland Mfg. Co.)*

FIGURE 5. - Plowing-In Cable With El Topo Cable Layer. *(Courtesy, Woodland Mfg. Co.)*

FIGURE 6. - Tractor-Mounted Cable-Laying Plow With Offset Mechanism.
(Courtesy, American Tractor Equipment Corp.)

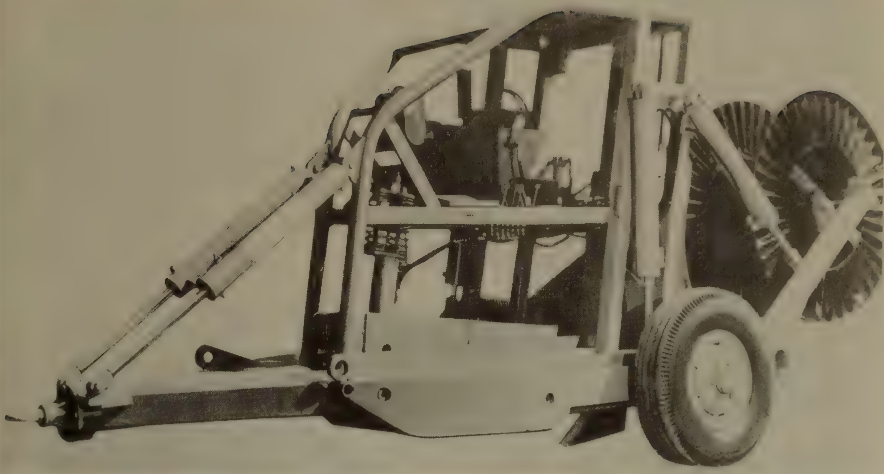

FIGURE 7. - Trailer-Mounted Cable-Laying Plow. *(Courtesy, Midwest Utility Plow & Equipment Corp.)*

with the same drawbar pull as a nonresonant system.[10] These resonant vibrating plows are currently in the research and development stages. Most and perhaps all of these resonant systems are based on the A. G. Bodine patents.

In addition to advantages of lower drawbar pull, vibratory plows have demonstrated an exceptional ability to cut through, move aside, or unearth subsurface obstructions. They tend to seek and maintain maximum depth and cause minimum surface damage.[11]

Speeds for pulling in vary from a few feet per minute under extremely difficult conditions to 200 fpm or more under extremely favorable conditions. Speeds for feeding in vary from only a few feet per minute to more than 100 fpm under ideal conditions. Resonant vibrating plows now under development promise speeds as high as 175 fpm or more.

Trenching

Trenching, another method of installing utility lines below ground, is probably the oldest method used for this task. Although the earliest trenching was done by hand, through the years sophisticated mechanical equipment has

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[10] Newfarmer, L. R. Sonic Tools for Plowing-In Cable, Pipe and Conduit Driving. Proc. AGA Distribution Conference, St. Louis, Mo., May 1-4, 1967 (in press).

[11] Work cited in footnote 8.

FIGURE 8. - Charles Vibratory Plow. *(Courtesy, Charles Machine Works, Inc.)*

FIGURE 9. - Parsons Vibratory Plow. *(Courtesy, Parsons, Division of Koehring Co.)*

been developed to increase trenching efficiency. Today trenching using the variety of equipment is a widely used utility burial technique.

Trenching machines are of at least three distinct types, the wheel type (fig. 10), the frost-cutter type (fig. 11), and the more conventional chain type (also called ladder type) (fig. 12). The versatility of the chain trencher is apparent in figure 13, illustrating an offset accessory for trenching near a building wall. Another machine capable of digging trenches is the familiar backhoe.

One rather unusual combination trencher is the Vermeer T-600 (fig. 14), a chain-type trencher with an integral vibrating plow. The vibrating plow allows feeding in a cable to a depth of 15 in below the trench bottom.

Another combination trencher, the Fruehauf Trackmaster (fig. 15), has a conventional cutter bar on one end and a backhoe on the other. This versatile unit can dig out a trenchline with either the backhoe or the cutter bar and dig access holes with the backhoe. Access holes or trenches are often necessary where laterals connect to the main line or anywhere that splicers are to be made. The backhoe-and-cutter-bar combination provides the versatility necessary to cope with a variety of materials typically encountered along a right-of-way. The Trackmaster also mounts a bulldozer blade for backfilling the trench.

A third combination machine has a cutter bar on one end and a vibratory plow on the opposite end. The cable spool mounted overhead at the machine center feeds cable into the ground either behind the cutter bar or through the plow. This machine also has a bulldozer blade for backfilling the trenches.

Most of the chain trenchers have removable, replaceable cutting elements as well as devices for casting the spoil to one side, thus leaving one side of the trench clean.

Chain trenchers can cut trenches 4 to 6 in wide and 80 in deep or more. Trenches 24 in wide can be cut to a depth of 24 in. These machines can cope with materials such as ice, frozen soil, clay, soft rock, and soils full of plant roots.

Trenching rates with chain-type machines depend on soil conditions and equipment capabilities and vary from only a few feet per minute to more than 40 fpm.

Backhoes can trench from a few feet in depth to more than 18 ft in depth and have bucket widths from 12 to 38 in. The bucket capacities vary from 1 or 2 cu ft to more than 10 cu ft.

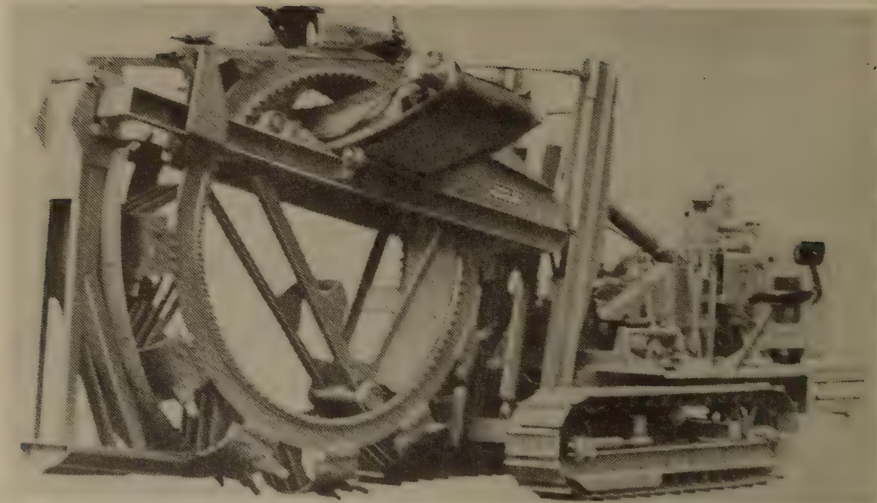

FIGURE 10. - Wheel-Type Trenching Machine. *(Courtesy, Parsons, Division of Koehring Co.)*

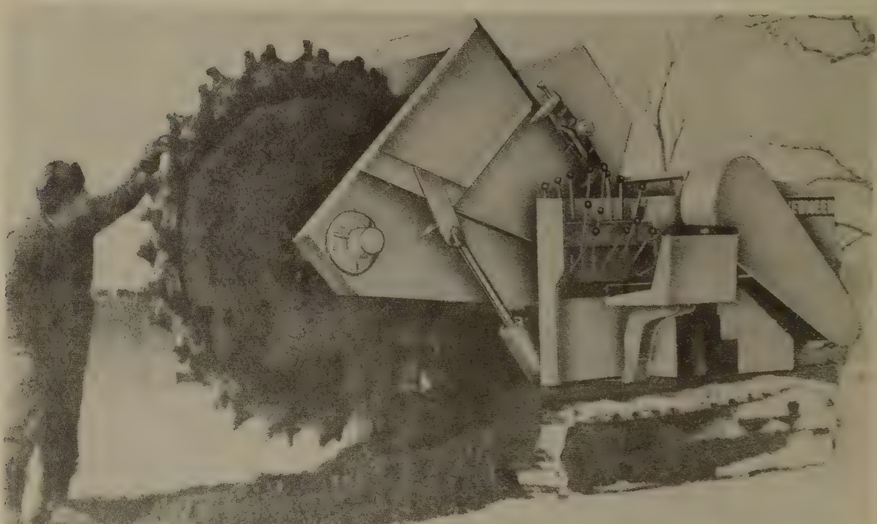

FIGURE 11. - Frost-Cutting Attachment on Trenching Machine. *(Courtesy, Vermeer Mfg. Co.)*

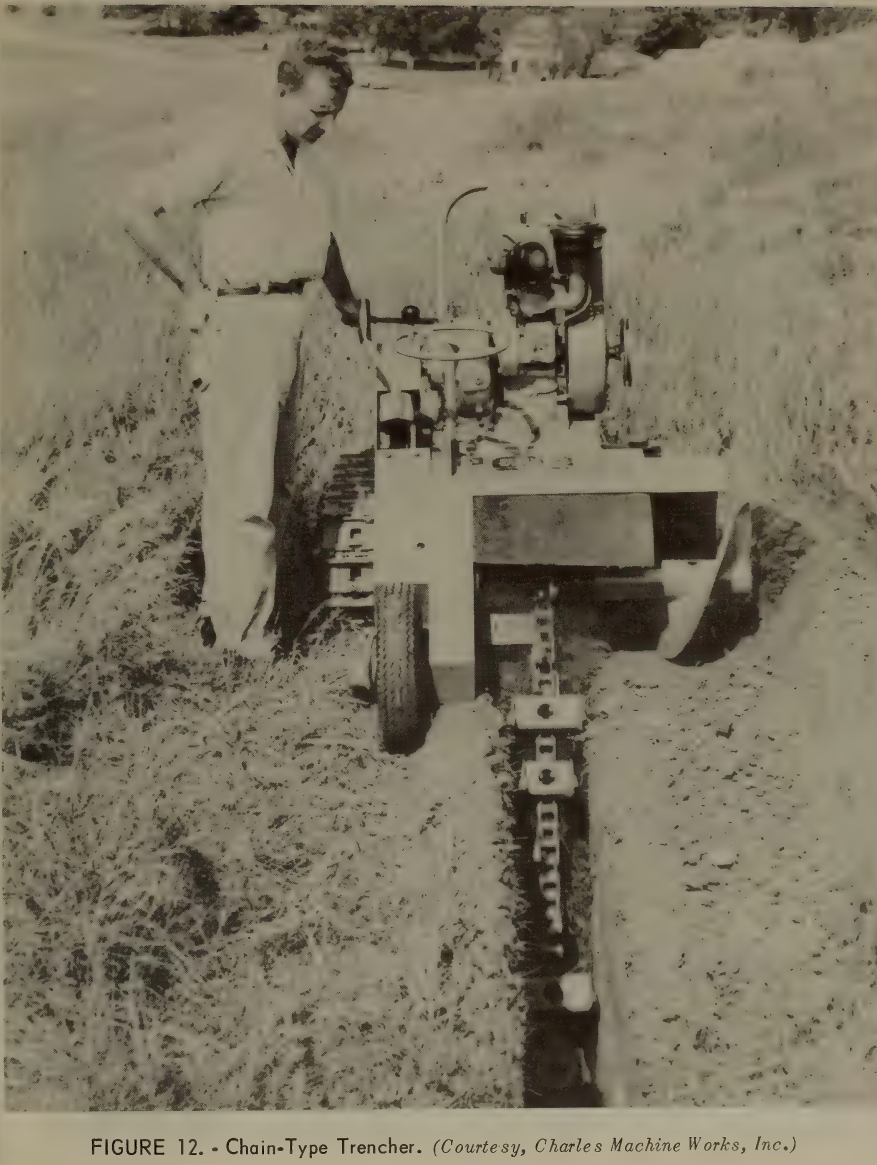

FIGURE 12. - Chain-Type Trencher. *(Courtesy, Charles Machine Works, Inc.)*

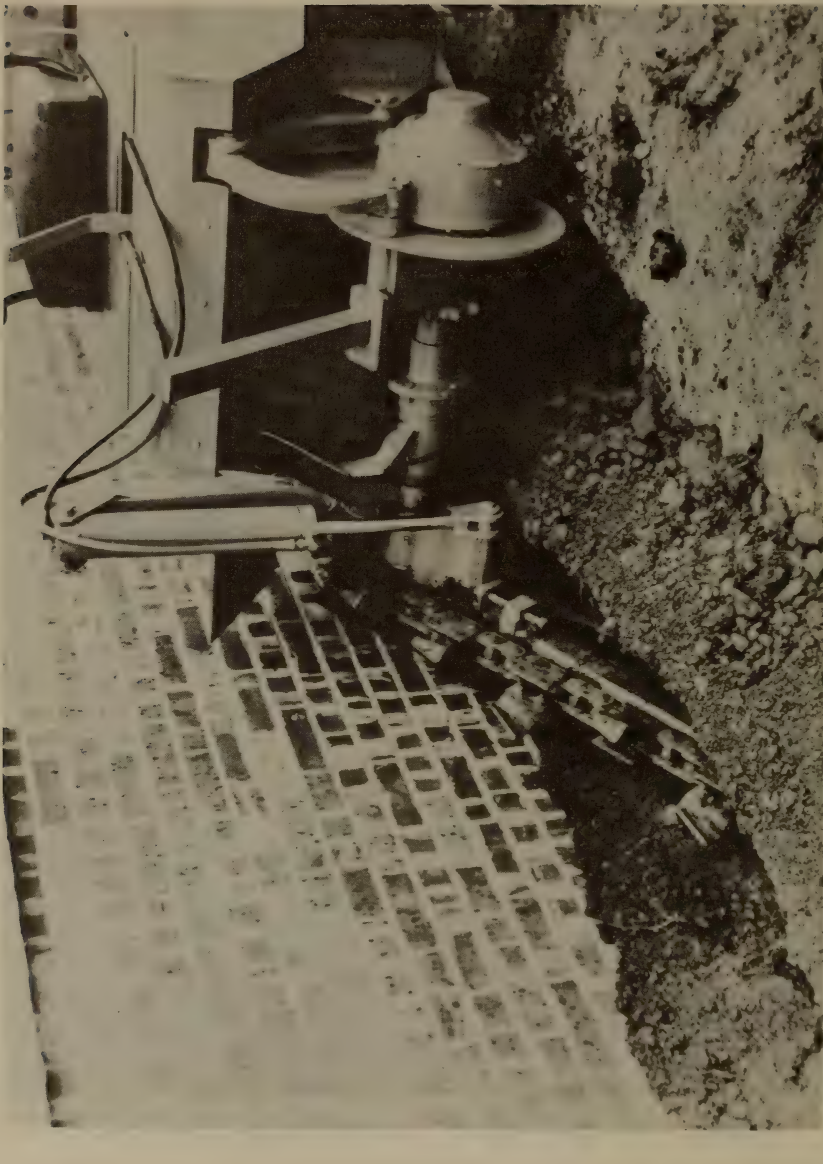

FIGURE 13. - Chain-Type Trencher With Offset Pivot. *(Courtesy, Charles Machine Works, Inc.)*

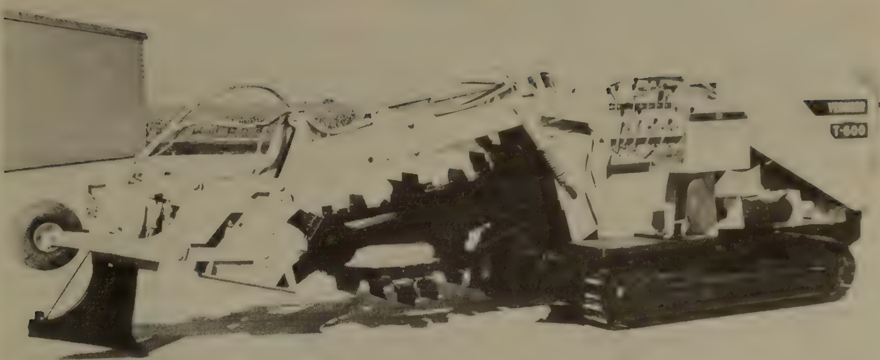

FIGURE 14. - Combination Trencher and Vibratory Plow. *(Courtesy, Vermeer Mfg. Co.)*

FIGURE 15. - Combination-Type Trencher. *(Courtesy, D-Fab Division of the Fruehauf Corp.)*

Costs

This section compares costs of the three most commonly used nonboring methods of installing power lines: plowing, trenching, and overhead. Although only scanty data on underground installation of high-voltage transmission lines are available, much information is available on the lower voltage distribution lines placed by each of the methods named.

Cost Comparison, Underground and Overhead Installation

Recent trends in underground distribution give some insight into the future of the underground emplacement of transmission lines. Developments in equipment and techniques have now lowered installation costs of underground distribution systems to levels approaching those of overhead installation.

In a recent British installation 3,300 yd of 132-kv polyvinyl chloride-sheathed, oil-filled, partially armored conduit was placed underground in two parallel trenches at a cost 12 times that of an overhead system.[12]

At the Los Angeles Department of Water and Power the ratio of the cost of underground to overhead emplacement was 2 to 1 for residential distribution, 5 to 1 for a double circuit 34.5-kv line, and from 6 to 1 to 8 to 1 for a double-circuit 230-kv transmission line.[13] Others report that a 275-kv insulated cable costs about 16 times as much as an overhead line of equivalent capacity.[14]

Another source reported that 10 years ago the cost ratio of going underground for residential distribution compared to overhead installation was 10 to 1; today in some instances it is 1.5 to 1. Installation costs of underground transmission lines were also reported to be as high as 20 times those of overhead transmission lines.[15]

Huston reports that the Pennsylvania Electric Co. experimental underground distribution program includes the installation of an underground system similar to present overhead systems and the plowing in of all cables that are plowable. Primary cables are being emplaced with Midwest Interline and Mainline plows adapted for plowing in three phases simultaneously. Table 2 shows a comparison between estimated overhead and underground costs.[16]

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[12] Electrical Distribution. Steep--But Amenities Preserved. January 1964, pp. 100-101.

[13] Blatt, R. C. Electric Light and Power Special Report. Utilities Develop New Techniques to Cut Underground T & D Costs. Elec. Light and Power, v. 43, No. 4, April 1965, pp. 54-65.

[14] Sayers, D. P. Electrical Transmission. J. Inst. Fuel, v. 33, May 1960, pp. 247-249.

[15] Proceedings of the White House Conference on Natural Beauty. Beauty for America. May 24-25, 1965, pp. 360-365.

[16] Huston, G. H. Brute Force is Used to Plow-In Primary Cables. Transmission and Distribution, v. 19, No. 6, June 1967, pp. 46-47.

TABLE 2. - Cost comparison between overhead and plowed cable

Job	Length of line, ft	Type	Estimated overhead cost	Actual underground cost	Plowed cost per foot
Lynn Run.........	11,000	Single-phase	$19,900	$14,200	$0.53
Galeton..........	4,200	....do......	8,300	5,600	.47
Kinzua Dam.......	4,000	Three-phase	7,100	8,300	.42
Dew Drop Inn.....	10,300	Single-phase	10,900	9,700	.30

Cost Comparison, Plowing and Trenching

Mr. Don Killoren of Killoren Co., and Mr. S. P. Balcomb of the Midwest Utility Plow & Equipment Corp., a Killoren Co. subsidiary, report that a good rule of thumb is that trenching, laying, and backfilling will cost 10 times more than direct plow burial. The average cost for plowing telephone cable is 5 to 6 cents per foot, including cable handling, and as low as 3½ cents per foot under ideal conditions. About the lowest cost that can be expected for trenching, laying, and backfilling is 75 cents per foot. Killoren and Balcomb also express confidence that they would have no problem placing larger sized, higher voltage lines underground.[17]

In evaluating plowing and trenching, it must be kept in mind that each has its specific applications. If either plows or trenching machines are improperly applied, to the wrong material for example, disproportionate costs will result. Some utility companies report trenching costs as low as 50 cents per foot while some manufacturers advertise plowing costs of only 2 cents per foot.

Schreiber reports that Cincinnati Gas and Electric Co. presently installs 800,000 to 1,000,000 ft of transmission and distribution pipe per year; his figures (table 3) show that plowing can significantly cut the cost of gas-main installation in congested areas not yet in the final stage of development.[18]

Atwood reports that Houston Natural Gas Corp. experience with both trenching and plowing indicates that the plowing technique can reduce labor and equipment costs by as much as 35 percent. The data shown in table 4 are based on this company's experience with the Ryan Model C plow.[19]

In 1967 Schnare described the history of plowing of the Northern Illinois Gas Co. as well as the equipment used, problems encountered and their solution, and economics. His data (table 5) compare the costs of plowing and of trenching for a variety of pipe diameters.[20]

[17]Mr. S. P. Balcomb, Vice-President and General Manager of Midwest Utility Plow & Equipment Corporation, Appleton, Wis. Personal Communication. Available at Twin Cities Mining Research Center, Minneapolis, Minn.
[18]Schreiber, James F., Experience with Plowing-In Gas Mains. Proc. AGA Distribution Conf., St. Louis, Mo., May 1-4, 1967 (in press).
[19]Atwood, John J. Economics of Plowed-In Pipe. Proc. AGA Distribution Conf., St. Louis, Mo., May 1-4, 1967 (in press).
[20]Schnare, R. E. Problems and Savings Associated with "Plowing". Proc. AGA Distribution Conf., St. Louis, Mo., May 1-4, 1967 (in press).

TABLE 3. - Costs of plowed and conventional gas-main installation

Total length, ft	Plowed pipe diameter, in	Percent plowed	Cost, company labor and equipment	Cost of rented equipment	Total cost per foot[1]		
					Plow	Conventional	Combined
1,607	2 and 4	70	$1,490.42	$142.06	$0.61	$1.73	$0.95
1,494	4	47	1,908.87	189.00	1.09	1.68	1.48
835	1¼	88	1,013.00	126.00	.91	4.68	1.36
1,000	2	70	1,271.00	115.00	.89	2.54	1.39
857	2 and 4	68	518.00	81.00	.48	1.16	.71
2,555	2 and 4	73	1,548.00	205.00	.59	.96	.69
1,075	2	78	1,054.00	58.00	.59	2.50	1.03
1,095	2	85	717.58	147.00	.35	1.00	.50
2,455	2	69	1,501.54	107.42	.32	1.40	.66
1,820	2 and 4	85	1,339.00	132.00	.48	2.62	.81
1,482	2	94	634.39	103.95	.31	3.25	.56
639	4	78	1,051.20	99.33	1.16	4.14	1.80

[1]Excluding material cost.

TABLE 4. - Labor and equipment costs for five projects using steel and plastic pipe

Job reference	Comments	Length installed, ft	Size, in	Type	Total labor, hr	Material[1]	Labor and equipment[1]	Cost[1]	Man-hours[1]
Humble Road......	Trenched, shoulder of road.	12,105	4	Steel	1,353	$116.00	$85.00	$201.00	11.4
Spring-Cypress Road.	First job with plow, shoulder of road.	36,860	4	do.	3,220	113.50	59.50	173.00	8.7
Northwood subdivision.	Plow, shoulder of road.	26,660	2	Plastic	1,039	53.00	31.00	84.00	3.9
Beverly Hills subdivision.	Trenched, utility easement.	13,630	2	Steel	1,134	53.40	50.60	104.00	8.3
Pine Oak subdivision.	Plow, roads, and easements.	13,677	2	Plastic	578	47.40	23.20	70.60	4.2

[1]All costs and man-hours are per 100 ft.

TABLE 5. - Comparison costs in 1966, plowing and trenching

	1-in diameter		2-in diameter	
	Plowed	Trenched	Plowed	Trenched
Average cost per foot.......	$0.88	$1.32	$1.18	$1.58
Total footage...............	111,000	159,000	183,000	102,000
Number of jobs..............	11	12	24	25
Average length........feet..	10,000	13,000	7,600	4,100
Longest job...........do...	28,000	39,000	38,500	14,000
Shortest job..........do...	1,000	2,500	500	500
Difference.........percent..	33	-	25	-
	3-in diameter		4-in diameter	
	Plowed	Trenched	Plowed	Trenched
Average cost per foot.......	$1.42	$1.95	$2.20	$2.43
Total footage...............	108,000	20,000	225,000	168,000
Number of jobs..............	3	2	15	20
Average length........feet..	36,000	10,000	15,000	8,400
Longest job...........do...	46,000	15,000	48,000	51,000
Shortest job..........do...	27,000	5,000	1,800	800
Difference.........percent..	27	-	9	-

Experience of Northern States Power Co., Minneapolis, with plowing, both pulling in and feeding in (also called planting) was described in a paper by Thompson. He shows figures for a variety of diameters in both plastic and steel pipe (table 6). He concludes that "a cost comparison is probably unfair to open trenching, but the statistics indicate a strong advantage for plowing where it is applicable."[21]

TABLE 6. - Comparison costs between plowing and trenching with steel or plastic pipe[1]

Location and type of construction	Item	Pipe diameter, inches				
		1	1½	2	3	4
Hugo, Minn.: Plastic pipe, plowed/planted.	Length (ft)	-	11,500	4,886	18,407	-
	Labor......	-	$0.35	$0.27	$0.40	-
	Material...	-	.30	.40	.76	-
	Other......	-	.59	.65	.68	-
	Total....	-	1.24	1.32	1.84	-
Various, Wisconsin:						
Plowed/planted.................	Total......	-	.88	.96	1.60	$1.51
Open trenched..................	Total......	-	1.92	2.02	2.83	-
Stillwater, Minn.:						
No. 1, plastic pipe, plowed/planted.[2]	Length (ft)	-	-	18,568	-	-
	Labor......	-	-	$0.12	-	-
	Material...	-	-	.37	-	-
	Other......	-	-	.28	-	-
	Total....	-	-	.77	-	-
No. 2 steel pipe, plowed.[2].....	Length (ft)	-	-	8,078	-	-
	Labor......	-	-	$0.22	-	-
	Material...	-	-	.50	-	-
	Other......	-	-	.30	-	-
	Total....	-	-	1.02	-	-

See footnotes at end of table.

[21] Thompson, Leonard N. Cost and Field Experience of Plowing-In Gas Pipe. Proc. AGA Distribution Conf., St. Louis, Mo., May 1-4, 1967 (in press).

TABLE 6. - Comparison costs between plowing and trenching with steel or plastic pipe[1]--Continued

Location and type of construction	Item	Pipe diameter, inches 1	1½	2	3	4
Stillwater, Minn.:--Continued						
No. 3 steel pipe, open trenched.[2]	Length (ft)	-	-	30,031	-	-
	Labor......	-	-	$0.64	-	-
	Material...	-	-	.52	-	-
	Other......	-	-	.89	-	-
	Total....	-	-	2.05	-	-
Wyoming, Minn.: Plastic pipe, plowed/planted.	Length (ft)	-	13,136	-	18,500	-
	Labor......	-	$0.28	$0.62	$0.59	-
	Material...	-	.31	.38	.79	-
	Other......	-	.53	1.38	.85	-
	Total....	-	1.12	2.38	2.23	-
Chisago, Minn.:						
Plastic pipe, plowed/planted...	Length (ft)	-	8,800	5,300	12,400	-
	Labor......	-	$0.36	$0.41	$0.37	-
	Material...	-	.31	.41	.81	-
	Other......	-	.53	.58	.57	-
	Total....	-	1.20	1.40	1.75	-
Steel pipe, open trenched......	Length (ft)	15,000	-	18,500	5,600	-
	Labor......	$0.61	-	$0.56	$0.37	-
	Material...	.29	-	.51	.81	-
	Other......	.61	-	.57	.57	-
	Total....	1.51	-	1.64	1.75	-
Lindstrom, Minn.:						
Plastic pipe, plowed/planted...	Length (ft)	-	770	-	2,000	546
	Labor......	-	$1.48	-	$1.43	$1.47
	Material...	-	.31	-	.80	1.13
	Other......	-	1.44	-	1.59	1.46
	Total....	-	3.23	-	3.82	5.06
Steel pipe, open trenched......	Length (ft)	1,600	-	10,500	6,100	-
	Labor......	$1.19	-	$1.05	$1.36	-
	Material...	.30	-	.54	.94	-
	Other......	1.13	-	1.14	1.35	-
	Total....	2.62	-	2.73	3.65	-
Center City, Minn.:						
Plastic pipe, plowed/planted...	Length (ft)	-	2,806	5,000	3,100	-
	Labor......	-	$0.46	$0.42	$0.61	-
	Material...	-	.32	.39	.81	-
	Other......	-	.82	.59	.82	-
	Total....	-	1.60	1.40	2.24	-
Steel pipe, open trenched......	Length (ft)	4,000	-	7,000	-	-
	Labor......	$1.10	-	$0.80	-	-
	Material...	.31	-	.52	-	-
	Other......	.85	-	.77	-	-
	Total....	2.26	-	2.09	-	-

[1]All costs are per foot.
[2]Continuous main extension along one highway with similar soil conditions, conditions of interference, etc.

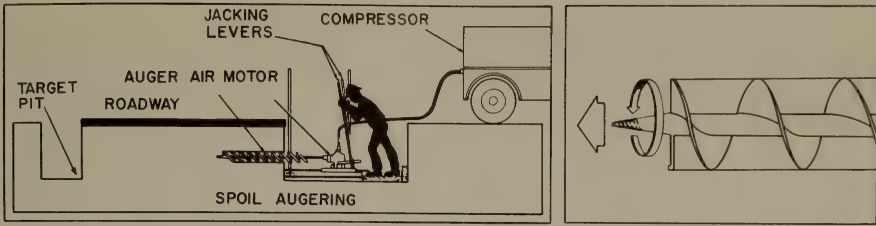

FIGURE 16. - Spoil-Augering Method. (Reproduced with permission of the Bell Laboratories RECORD.)

SOIL PENETRATING METHODS AND EQUIPMENT

The term "soil" or "earth" as used by engineers includes virtually every type of uncemented or partially cemented inorganic and organic material found in the ground.[22]

Spoil Augering

Essentially a three-component unit used to bore holes in soil or weak rock, an auger consists of a drag bit, an attached spiral conveyor, and a power source. The drag bit, pushed and rotated simultaneously, penetrates the soil while the spirals convey the cuttings out of the hole to a discard point. The spoil-augering method is shown in figure 16.

Augering Capabilities

Although augers function most effectively in soft materials (soils and soft shale or sandstone) which do not cave or slough readily, they can be used successfully in loose or caving material if the hole is cased simultaneously with augering. Augers do not operate well in soils containing rocks or boulders larger than one-third the auger diameter.

Current auger designs and models have straight-hole capability only. Augers can bore holes ranging in diameter from 2 to 84 in,[23] but most are in the 3- to 48-in-diam range.

Augering systems have been used to bore horizontal holes up to 574 ft[24] in length, but most horizontal augered holes are from 100 to 200 ft long.

Little information is available on the accuracy of augered holes, but a recently completed 285-ft hole was reported to be on target.[25]

[22] Bureau of Reclamation. Earth Manual. Denver, Colorado, 1st ed., June 1960, 751 pp.
[23] Coal Age, Augering. V. 72, No. 7, July 1967, p. 247.
[24] McNeil, Robert C. Pipeline Crossings Aren't Boring. Pipe Line Construction, v. 19, No. 6, May 1964, p. 28.
[25] Stihl Earth Drilling. Record-Setting Horizontal Drilling for Service Pit at Runway B, No. 4, 1962, p. 3.

Penetration rates are usually a function of hole diameter and the character of material bored. Reported rates for 24- to 36-in-diam holes range from 15 fph in hard material (shale, limestone) to 50 fph and more for soft materials (sands, clays, soils).[26] For smaller diameter holes the penetration rates will usually be greater than 50 fph.

Costs

Augering costs run about the same as for pipe pushing (see Pipe Pushing section). We have no cost data for small-diameter holes but for holes 12 in in diameter or more, the cost runs about $1.00 to $4.00 per inch of pipe diameter per foot of hole.

Operating Procedures

Augering proceeds from a pit dug to a depth at which the hole is to be bored. After the pit is completed, the equipment is lowered into the pit, alined with blocks or jacks, and checked with a transit and level for accuracy.

Boring may be done with the auger alone, with the addition of water to the system, or by casing the hole as boring progresses. The use of water and casing provides the continuous support for the hole usually required in drilling long holes. As the hole progresses new sections of auger must be added. Auger sections are available in various lengths and can be attached in 1 to 2 minutes. The sequence is continued until the hole breaks into the target pit. If the hole has not been cased, a reamer can be attached to the auger to enlarge the hole as the auger is backed out of the hole; similarly, casing may also be installed as the auger is withdrawn from the hole.

The accuracy of the augering device depends primarily on the original alinement of the equipment. When augering, various factors may cause the bit to wander from its predetermined course, particularly in smaller holes. Some augers have supports mounted behind the bit which can be shimmed to maintain the alinement of the hole[27] while others have channel iron mounted on the barrelhead to minimize deviation.[28] Many operators install observation pits every 50 to 75 ft along the target line to check the accuracy of the bore and make corrections as necessary.

Equipment

In a typical small auger system (fig. 17) power is provided by a 9.2-hp gasoline engine; the auger unit is mounted on a track 84 in long and 21-1/2 in wide. This unit can bore and case a 2-3/4-in hole about 120 ft long.

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[26] Samuelson, W. J., et al. Construction Techniques and Costs for Underground Emplacement of Nuclear Explosives. U.S. Army Engineer District, Fort Worth, Fort Worth, Tex., 1966, p. 20.

[27] Nutter, Homer P. Advances in Auger Mining Techniques, Min. Cong. J. v. 49, No. 9, September 1963, p. 32.

[28] Haydon, W. F., and Tom M. Shattuck. Underground Augering Under Difficult Seam Conditions. Min. Cong. J., v. 45, No. 11, November 1959, p. 41.

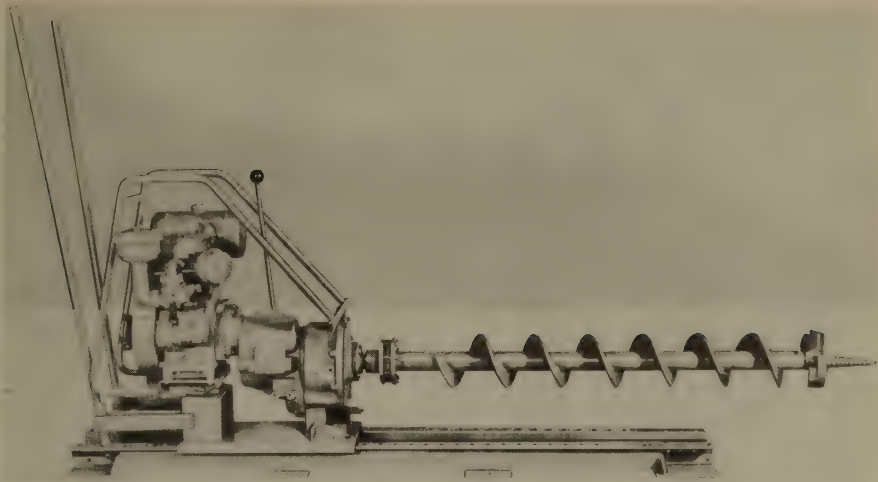


FIGURE 17. - Small Earth Auger. *(Courtesy, PCM, Division of Koehring Co.)*

A larger auger unit (fig. 18) is powered by a 63-hp gasoline or diesel engine, measuring 12¼ by 8½ by 3 ft and weighing about 6,800 lb. This unit can bore and case a 42-in-diam hole about 300 to 400 ft long.

The first auger section is equipped to take a variety of cutting tools in several combinations. Bits used in rock are equipped with tungsten carbide tools. Figure 19 shows some of the many different types of cutting heads available.

Compacting Augering

A compacting auger looks and acts much like a wood screw (fig. 20). As the bit rotates it compresses the soil around itself to form a natural earthen casing and provides its own forward pulling force in the same way that a wood screw does.[29]

Augering Capabilities

The compacting auger can be used in almost all soils except those containing large rocks. It can bore only straight holes to a maximum length of somewhat over 200 ft. Holes can be drilled up to 4 in in diameter on the first pass and can later be reamed to a maximum of 8 in.

In boring longer holes, the usual practice is to dig test pits every 100 ft or so to redirect the bit. This spacing of test pits, however, varies

[29]Milsark, D. Burying Wire and Cable Under Obstructions. Bell Laboratories RECORD, v. 45, No. 3, March 1967, pp. 71, 73.

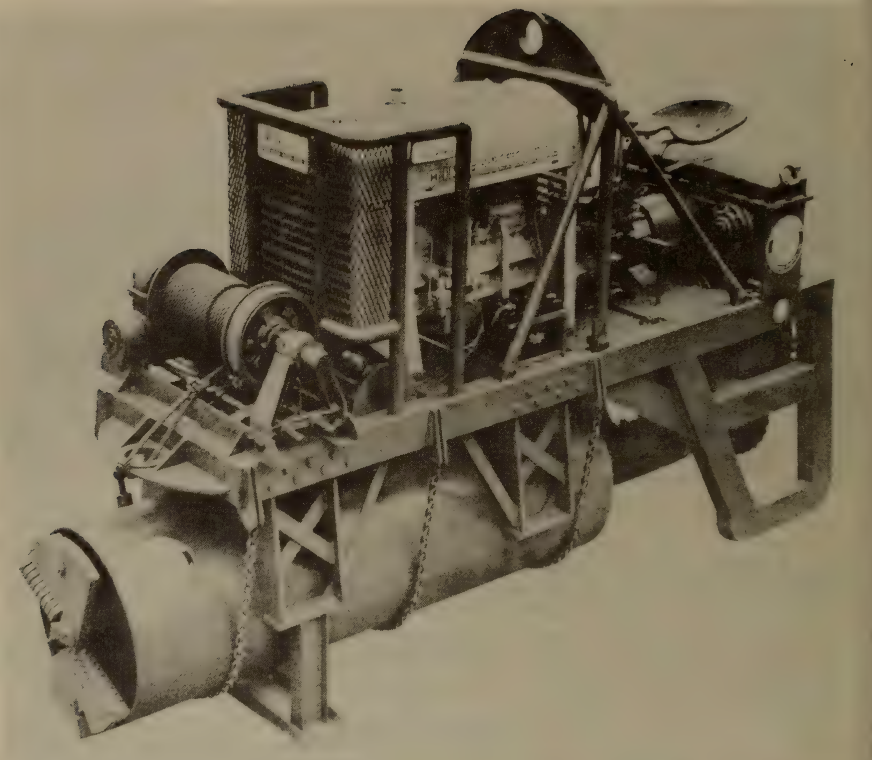


FIGURE 18. - Road-Boring Machine. *(Courtesy, CRC, Crose International, Inc.)*

with soil conditions. The auger reportedly wanders about 1° off course[30] which amounts to less than 1 ft of error in a 100-ft bore. Some holes drilled under ideal conditions have deviated by only a few inches in a 150-ft hole.

The penetration rate of a compacting auger ranges from 2 to 8 fpm depending on soil conditions. Under normal operating conditions, the average rate is 5 fpm.

Costs

A complete unit mounted on a cart costs $2,750; another type can be bought as an attachment for a small trencher for $700. Bit costs range from

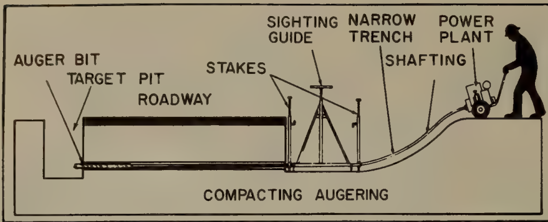
[30] Electrical World. Bubble Level, Plus Soil-Hardness Sensor, Could Ease URD Cable Work. V. 168, No. 6, Aug. 7, 1967, pp. 108-110.

FIGURE 19. - Auger Cutting Heads, Cutting Barrels, and Lump Breakers.
(Courtesy, The Salem Tool Co.)

$200 to $400 per year and boring costs, less equipment depreciation, may be as low as 13 cents per foot.

Operating Procedures

A line-of-sight trench is dug slightly deeper than the depth at which the hole is to be bored. This starting trench should be 4 to 6 in wide and should be about five times longer than the starting depth of the hole. The auger



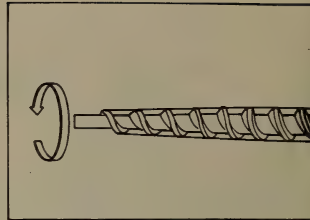


FIGURE 20. - Compacting Augering Method. (Reproduced with permission of the Bell Laboratories RECORD.)

head and drive shaft are alined in the trench with a simple guide tube and stakes. As the auger is rotated, it begins pulling itself through the ground and compacts it into a natural casing as it progresses. This natural earthen casing supports the hole long enough for the utility lines to be emplaced. If necessary, the pilot hole can be reamed to a larger size by attaching a reaming bit and running the tool back out of the hole. Successively larger reamers can be used until the desired diameter is achieved.

The compacting auger system has no in-process directional control; its only control is that of the original alinement.

Equipment

The auger is rotated by a mechanical or hydraulic drive unit which is usually powered by a small gasoline engine. The power unit and auger drive unit can be mounted as a complete package on a small two-wheeled cart (fig. 21) or the auger drive unit can be mounted as a special attachment on a small trenching unit.

Drilling heads with screwlike flights are made of heat-treated alloy steel. These drilling heads are available in diameters ranging from 1¼ to 4 in. Reaming heads similar to drilling heads in construction are available in diameters ranging from 1-5/8 to 8 in.

The alloy steel driving rods may be solid or hollow depending on whether or not water is used and are semiflexible to allow the auger drive unit to remain on the surface.

The control equipment consists of a sighting guide and positioning stakes.

Drilling head, reamer, drive rods, and control equipment are shown in figure 21.

Water Boring

The water-boring system[31] uses a drag bit attached to a hollow drill string powered by a hydraulic motor, air motor, or conventional rotary equipment such as used in auger systems. The bit, commonly called a fish-tail bit,

[31]Most of the data on water-boring describe equipment manufactured by Melfred Welding and Mfg., Inc.

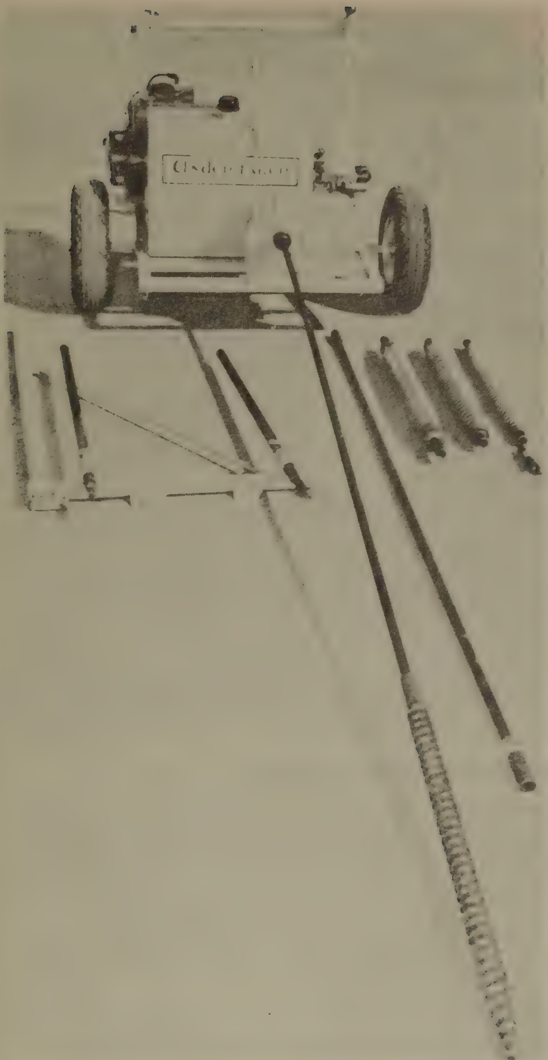


FIGURE 21. - Compacting Auger With Drilling Head, Reamers, Extension Rods, and Sighting Accessories. *(Courtesy, Contender Corp.)*

is pushed and simultaneously rotated into the soil while water is pumped through the drill string to the bit (fig. 22). The water aids the cutting action of the bit and also serves to flush the cuttings back out of the hole.

Boring Capabilities

Water boring is applicable to all soils free of large rocks or boulders as well as to such soft massive rock formations as soft sandstone or shale. Like augering methods, water boring has straight-hole capability only.

Although the longest hole bored with this system is not known, the equipment reportedly has a capability of 500 ft. Holes can be bored up to 4 in in diameter on the first pass and can later be reamed up to 18 in in diameter.

Because of its high torque requirements, the bit tends to wander and pits must be dug every 35 ft or so to redirect the bit.[32] Penetration rate data are not available but they are probably similar to those of augering systems.

A typical water-boring system (fig. 23) is powered by an air motor, mounted on a drill rack $12\frac{1}{2}$ ft long, 14 in wide, and weighs 195 lb.

[32] Page 71 of work cited in footnote 29.

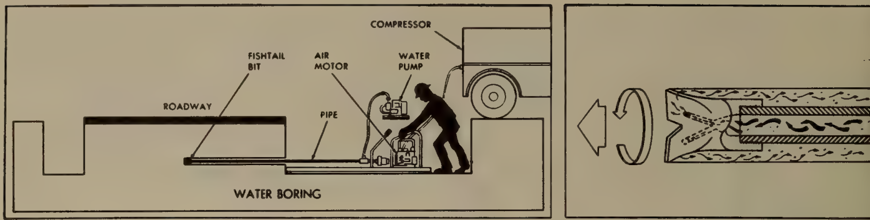


FIGURE 22. - Water-Boring Method. (Reproduced with permission of the Bell Laboratories RECORD.)

The drilling head consists of drag bits with either two or three blades that can be equipped with tungsten carbide inserts for boring in hard formations.

The bits shown in figure 24 may range from 2 to 4 in or more in diameter. Reamers 4 to 20 in in diameter are available with either two or three blades and can be of either push or pull variety. The blades are usually hard faced to minimize wear (figs. 25 and 26).

Drill rods are constructed of steel tubing and are usually available in lengths of 5, 10, or 20 ft.

Special alinement equipment is available and consists of alinement stakes, sighting device, and target (fig. 27).

Costs

Costs and operating procedures are similar to those described under Spoil Augering.

Impact Penetrating (Mechanical Mole)

The mechanical mole[33] consists of an air-driven reciprocating hammer and an anvil enclosed in a steel, bullet-shaped housing (fig. 28). Air for the hammer is supplied by a trailing air hose connected to an air compressor outside of the hole. The hammer's impact against the anvil drives the tool forward through the soil and compacts it into a natural earthen casing. The casing supports the hole long enough to install the desired utility.

Mole Capabilities

The mole may be used in any soils except those containing large rocks or boulders. The method has straight-hole capability only and can bore a 3-3/4-in-diam hole up to 100 ft in length. This pilot hole can later be enlarged to a maximum diameter of 5-7/8 in.

[33]Most of the information for this section describes the PneumaGopher manufactured by Schramm, Inc.

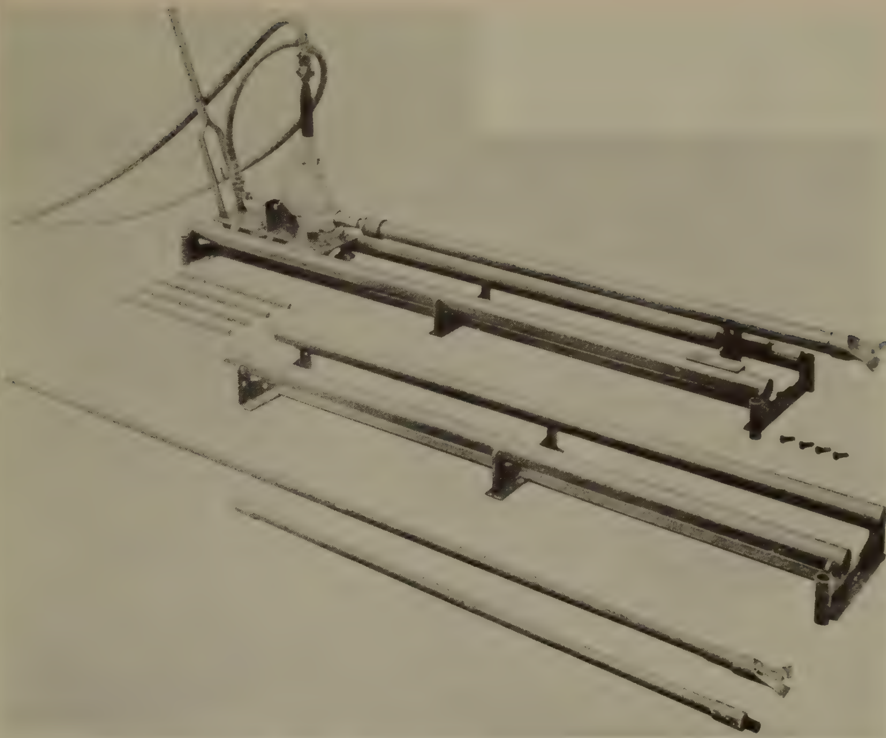


FIGURE 23. - Air-Powered Water-Boring Drill Mounted on Drill Rack.
(Courtesy, Melfred Welding and Mfg., Inc.)

The penetration rates for this method range from 60 to 240 fph depending on soil type.

Costs

Operating costs with the mechanical mole are not available. The cost of equipment is $1,580 exclusive of compressor.

Operating Procedures

The mole is started into the soil, then stopped and alined. Alinement may be made by eye or with transit and level. The mole must be started at a certain minimum depth below the surface or it will tend to surface. The manufacturer provides data on the minimum starting depths for various soils.

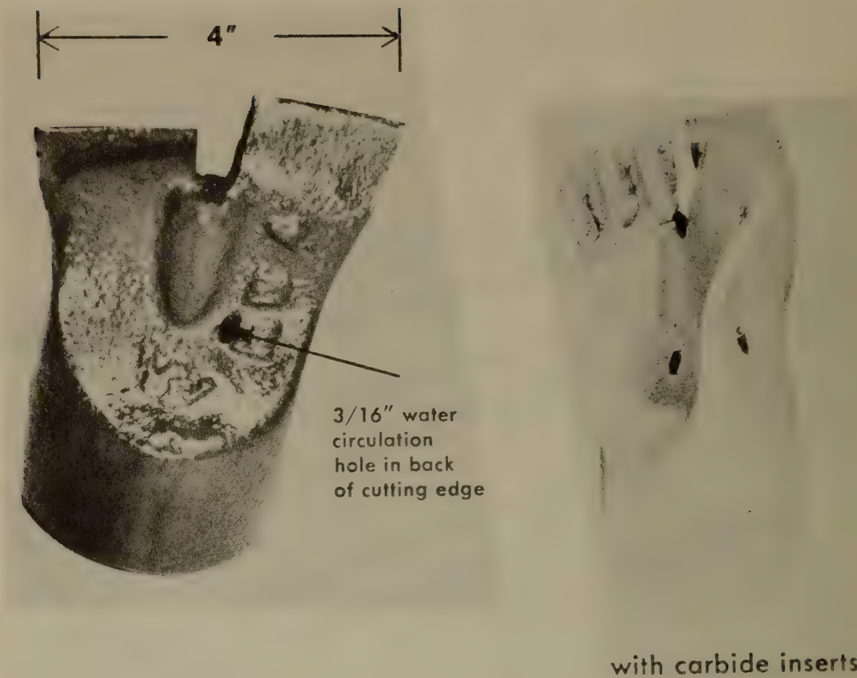


FIGURE 24. - Fish-Tail Drag Bits. *(Courtesy, Melfred Welding and Mfg., Inc.)*

When compressed air is supplied, a reciprocating hammer drives the bullet-shaped mole through the soil. The mole does not push the soil in front or behind it but instead compacts it around itself to form a natural casing. This earthen casing allows sufficient time to install the utility lines before it collapses. The head of the mole is equipped with a star bit and while not designed to penetrate rock formations it can reportedly shatter small rocks directly in its path.

The pilot hole may be enlarged up to 5-7/8 in by attaching slip-on collars to the mole. These collars effectively increase the diameter of the mole body and permit larger openings to be made.

There is no in-process directional control over the mole; for long holes test pits could be dug at intervals along the target line to intercept the mole and redirect it as necessary.

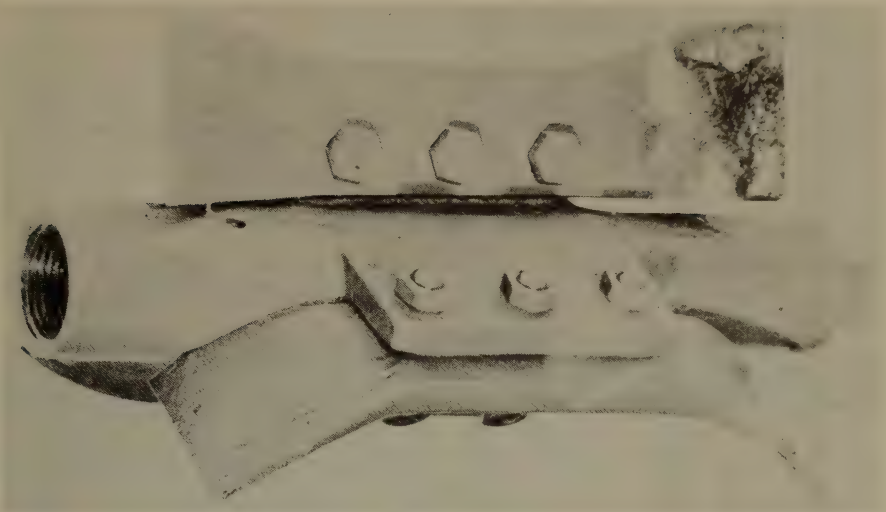


FIGURE 25. - Three-Bladed Earth Reamer. *(Courtesy, Melfred Welding and Mfg., Inc.)*

FIGURE 26. - Two-Bladed Earth Reamer. *(Courtesy, Melfred Welding and Mfg., Inc.)*

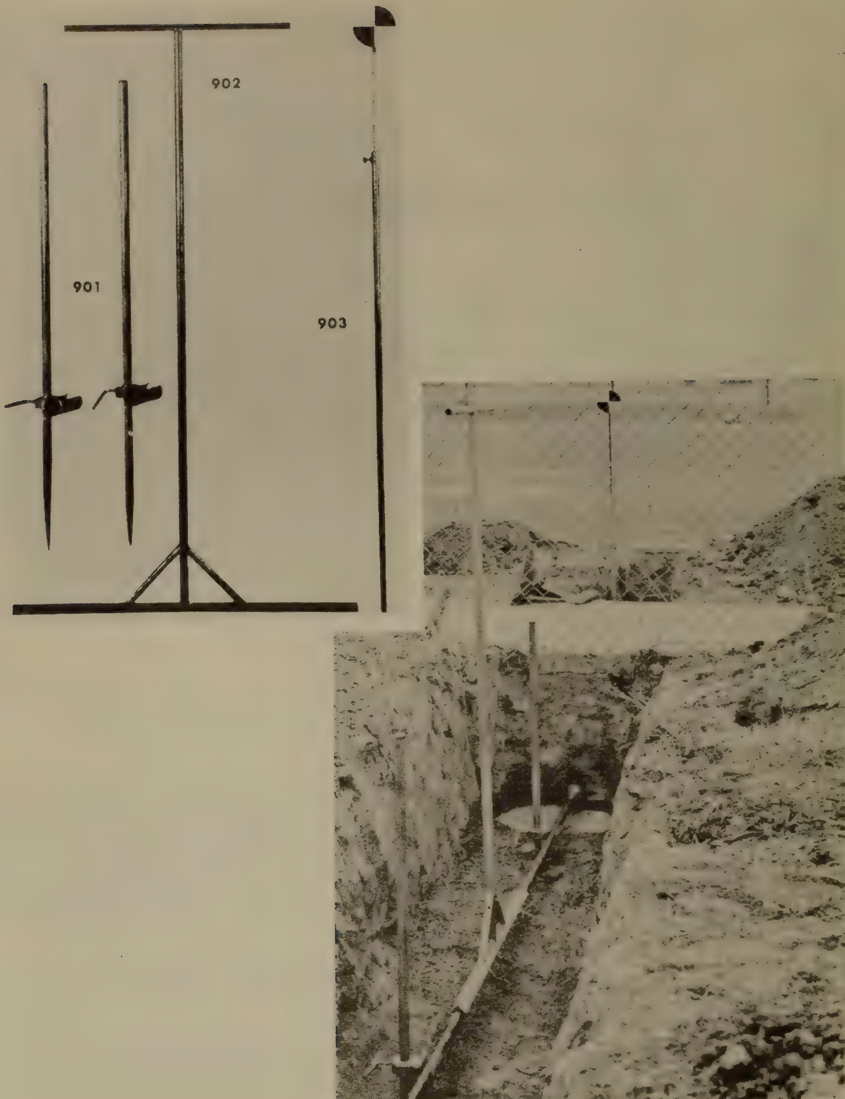


FIGURE 27. - Sighting Equipment for Alinement of Drill Rod and Bit.
(Courtesy, Melfred Welding and Mfg., Inc.)

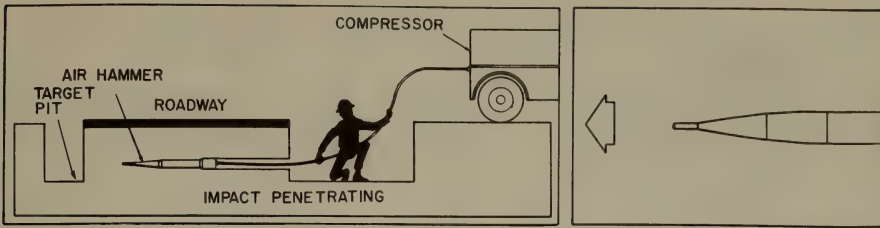


FIGURE 28. - Impact Penetration With Mechanical Mole. (Reproduced with permission of the Bell Laboratories RECORD.)

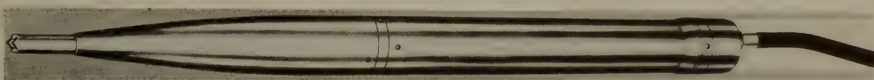


FIGURE 29. - PneumaGopher. *(Courtesy, Schramm, Inc.)*

Equipment

The mechanical mole uses 45 to 50 cfm of air at 90 psi supplied from a separate air compressor. The mole is 45 in long, its diameter without collars is 3-3/4 in and its weight is 64 lb (fig. 29).

Air is supplied to the mole through a flexible air hose. Under proper conditions, the utility line (hollow gas line, etc.) may be used in place of the air hose, a procedure which eliminates fishing through the line after the hole is completed. Reaming collars to enlarge the hole are shown in figure 30.

Pipe Pushing or Jacking

Pipe jacking or pipe pushing is a technique of statically forcing lengths of rigid pipe through the soil, usually by means of a hydraulic ram. Since this technique requires high forces, sometimes in excess of 800 tons, the rear wall of the starting pit must be securely shored up with timbers to resist the reaction force. A hydraulic pipe-pushing method is shown in figure 31.

Pushing Characteristics

Pipe-pushing methods can be used in most soils. Those soils containing large rocks or boulders or close-packed sandy soils[34] may present problems

[34]Electrical Construction and Maintenance. Underground Work. V. 63, No. 7, July 1962, pp. 116-119.

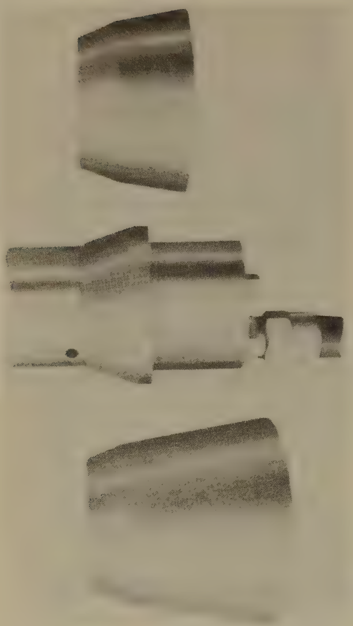


FIGURE 30. - Reaming Collars for PneumaGopher.
(Courtesy, Schramm, Inc.)

with this method. Pipe pushing or jacking has straight-hole capability only.

Lengths of hole achieved by pipe pushing range from 100 to 200 ft depending on equipment, while the diameter of the hole ranges from a few inches to a maximum of 9 ft.

A high degree of accuracy can be achieved by this method with 2 ft or larger diameter pipes that have been carefully alined; deviations of 1 ft or less in 100-ft bores are not uncommon. Smaller diameter pipes are usually pushed less accurately because they are more easily deflected.

Penetration rates are a function of soil, thickness of pipe wall, and available power unit. A rough estimate of the penetration rate is 6 to 12 fph[35] for small-diameter pipes and 1 fph for large-diameter pipes.

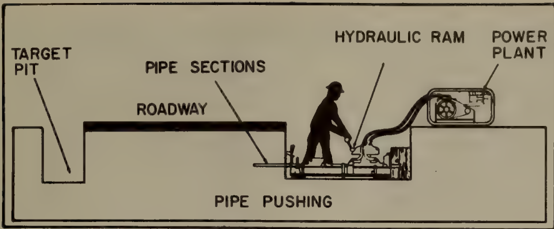
Costs

The cost of pipe pushing has been reported at $1.90 per ft for 3- to 4-in-diam pipe,[36] while costs for larger pipes (12- to 30-in-diam) usually ranges from $1.50 to $4.00 per inch of pipe diameter per foot of hole.

Operating Procedures

The pipe-pushing system is set up in a pit dug slightly deeper than the depth at which the hole is to be made. A hydraulic ram is then lowered into the pit, securely positioned against timbers to resist the reaction force, and alined by eye or with a level and transit. An engine-driven pump supplies fluid to the hydraulic ram which forces the attached pipe into the soil. As each pipe section penetrates the soil, new lengths are welded on and jacking continues. If the spoil is not removed continuously as the pipe is driven, the jack pressure begins to increase because of resistance of the material being displaced by the pipe; pressure buildup signals the end of the pipe pressing operation and the beginning of the spoil removal. This pressure

[35] Luskin, A. Ya. Laying Pipe Without Trenches by the Vibro-Boring Method. Novaya Tekhnika Montazhnykh I, Spetsial' nykh Rabot V Stroitel' stve, v. 21, No. 12, December 1959, p. 1.
[36] Page 119 of work cited in footnote 34.



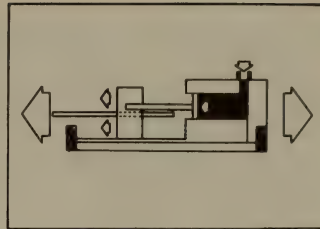


FIGURE 31. - Pipe-Pushing Method. (Reproduced with permission of the Bell Laboratories RECORD.)

buildup must be closely watched because if left unchecked, it can cause heaving or buckling of the surface. In pushing large-diameter pipes the spoil or plug is removed manually with spades, jackhammers, or water jets; in small diameters an auger or water jets can be used to remove the spoil. After the spoil is removed and the resistive pressure relieved, the pressing operation begins again and the cycle is repeated. To reduce the sidewall friction of the entering pipe, the leading pipe is often equipped with nozzles through which a bentonite slurry can be pumped into the formation. This slurry also serves to control the tendency of the hole to cave. Since the original ram still may not have enough thrust to complete the bore on a long hole, intermediate stations dug along the line can provide the additional thrust as well as direct the pipe on course as necessary.

Since this system has no in-process directional control over the pipe except as noted above, the original alinement must be accurate if the hole is to be on target.

Equipment

A hydraulic pump powered by a gasoline engine generally supplies the pushing force. The largest hydraulic cylinders supplied by these pumps can provide forces in excess of 800 tons. Figure 32 shows a hydraulically operated ram for pipe-pushing operations.

The leading steel or concrete pipe itself forms the drilling head and in the larger sizes is usually equipped with nozzles. These pipes range from a few inches to 9 ft in diameter.

Overburden Drilling

The overburden drilling method (fig. 33) utilizes a percussive drill with independent rotary action operating inside a casing which is simultaneously emplaced as the hole is formed.[37] Although this method is used principally for vertical holes, it has also been used for horizontal boring. It is applicable to any variety of soil or to rock formations because the percussive

[37] The overburden drill is manufactured by Atlas Copco.

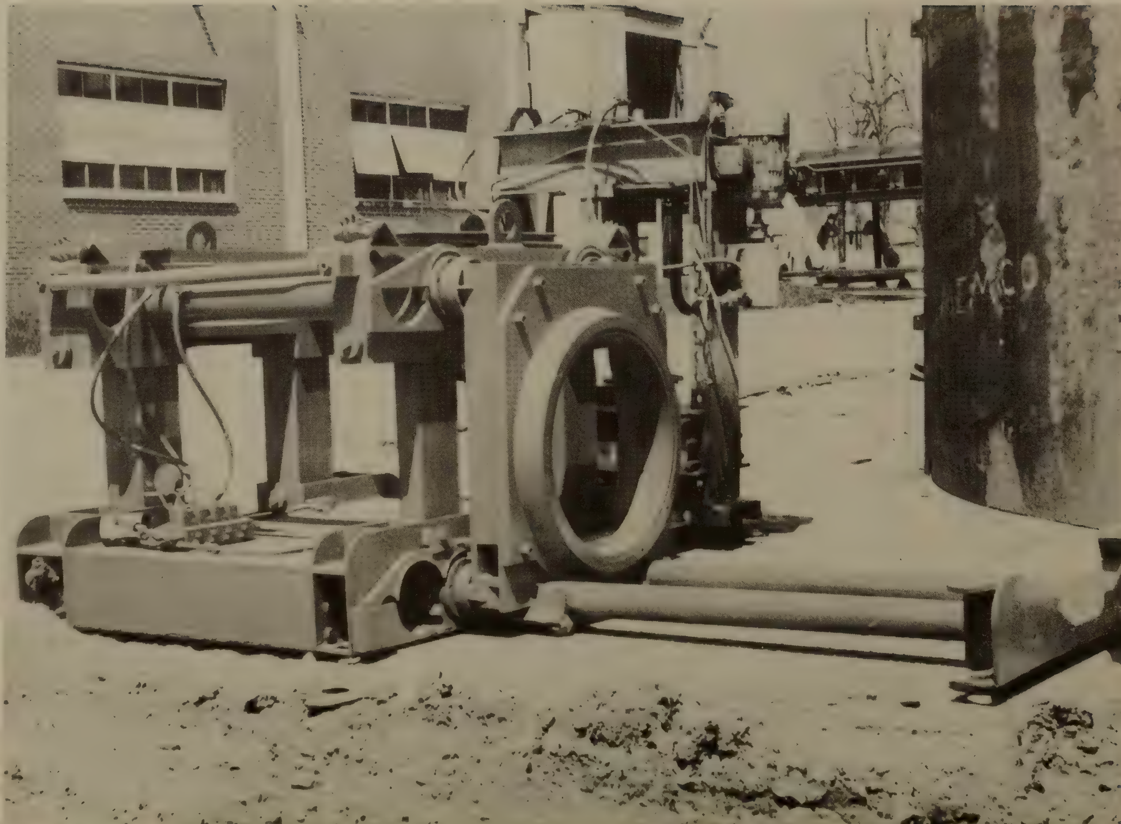


FIGURE 32. - Pipe Pusher. *(Courtesy, Mining Equipment Mfg. Co.)*

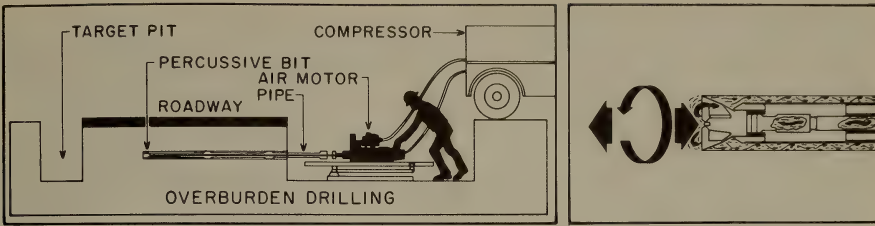


FIGURE 33. - Overburden Drilling Method. *(Courtesy, Atlas Copco.)*

drill can penetrate either soils or rock, and the casing supports the hole in soft material. Chips or spoil are removed from the hole by the action of powerful jets of air or water.

Drilling Capabilities

The overburden drilling method is applicable to any material including soils, gravels, boulders, and rock formations. The percussive drill can bore a 4-in-diam hole over 100 ft in length. It has only straight-hole capability.

Drilling accuracy with this method amounts to about 1 percent of the length of the hole; that is, in a 100-ft hole the error would be about 1 ft.

Although penetration rates are a function of the material drilled, Atlas Copco reports a penetration rate of 0.44 fpm in gravel and broken rock.

Operating Procedures

The drill and carriage, measuring 15 ft long and 6 ft wide overall, are lowered into a suitable starting pit. Alinement is made by eye or with a level and transit.

As drilling begins, the rotary percussive action of the bit breaks up the material; air or water is used to flush the cuttings out of the hole. In soft material the jetting action of the water significantly aids the bit action in achieving high penetration rates. After the bit has penetrated some distance, extensions are added to both the inner drill rods and the outer casing and the process is repeated.

Since there is no in-process directional control, the original alinement of the drill must be accurate.

The hole remains open under all conditions because it is continuously being lined and supported by the outer casing as drilling advances.

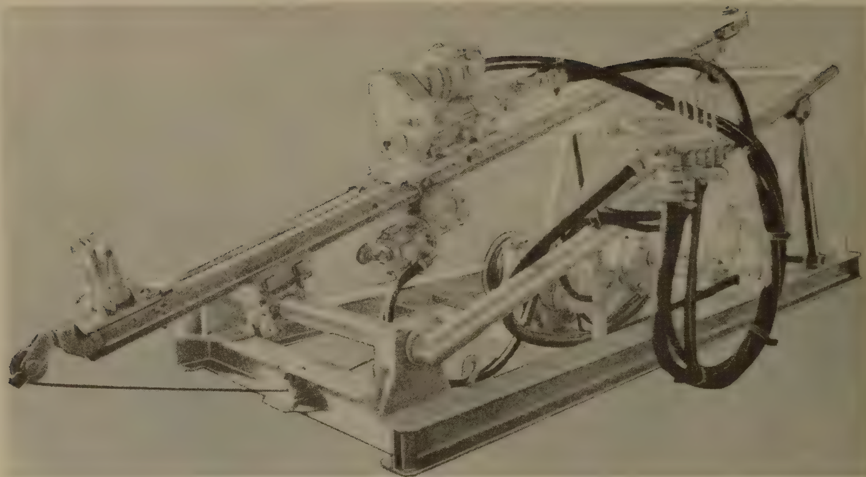


FIGURE 34. - Horizontal Overburden Drill. *(Courtesy, Atlas Copco.)*

Equipment

The drill is powered by an air motor that requires 440 to 545 cfm at 100 psi. The drill unit, consisting of the drill motor and mounting, is 15 ft long, 6 ft wide, $2\frac{1}{2}$ ft high, and weighs 3,000 lb.

The drilling head is a carbide-tipped percussive bit with a maximum diameter of 5 in.

The inner drill rods transmitting the energy to the bit are standard $1\frac{1}{2}$-in rods. The outside pipe or casing supporting the hole is 4 in in diameter. The horizontal overburden drill is shown in figure 34.

Vibratory (Sonic) Conduit Driving

Metal pipes resonating at their fundamental frequencies can be pushed more efficiently than those driven with conventional pipe-pushing methods (fig. 35). The only long horizontal holes driven in the United States with this method have utilized the Bodine resonant vibrator. Others[38] have done work on horizontal pipe driving which utilized vibrations without resonance, but their penetration rates are less than those of the Bodine resonant driver.

[38]Pages 26-28 of work cited in footnote 35.

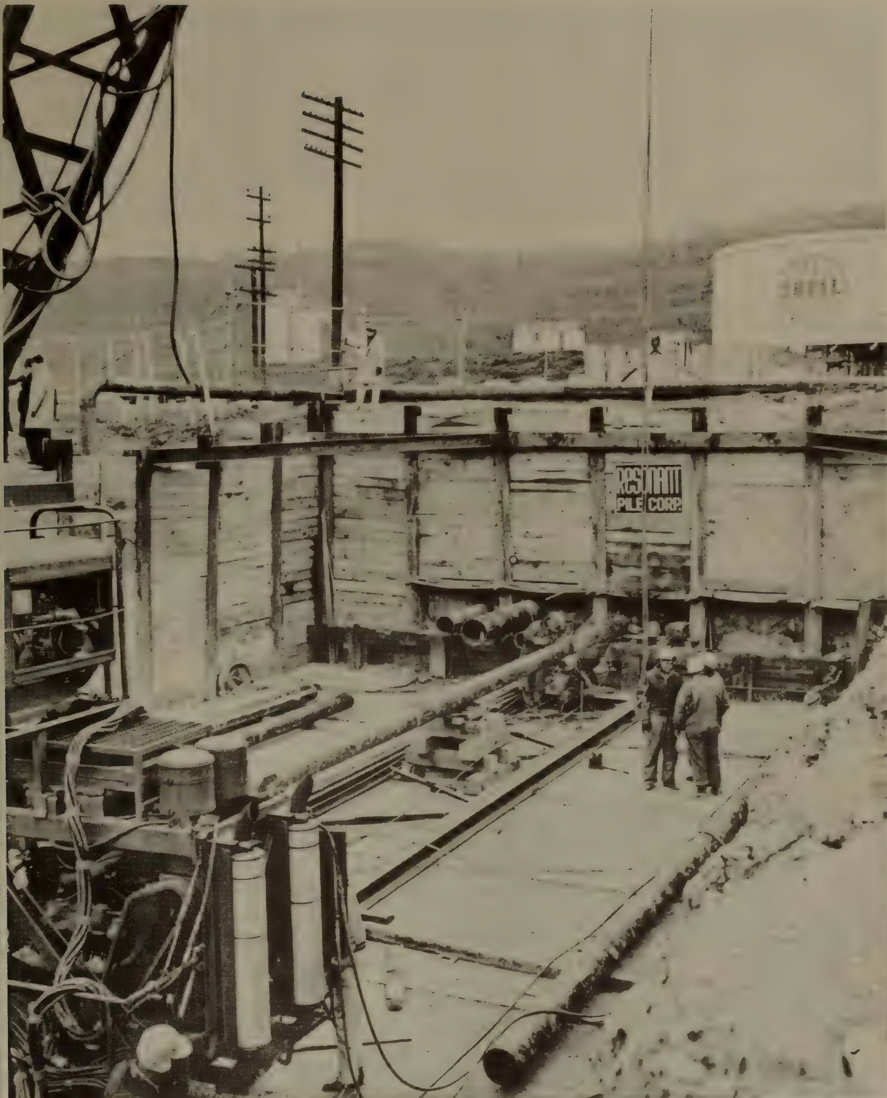


FIGURE 35. - Resonant-Vibratory Conduit Driver. *(Courtesy, SoniCo Inc.)*

The vibratory method[39] of driving rigid metal conduit through the soil utilizes the random motion response of soils to forced vibrations and the corresponding decrease in the resistance of soils which these vibrations induce. The vibrations (waves) are set up in the pipes to be emplaced by a variable frequency mechanical exciter operating at frequencies ranging from 0 to 200 cps and with a power range of up to 1,000 hp. Since these waves are reinforced and amplified in the pipe by the resonance effect, a large amount of energy becomes available for reducing resistance. This reduction in soil resistance can decrease the force necessary to drive a pipe through the soil by as much as 98 percent.[40]

Drilling Capabilities

The only material in which vibratory means have been used to drive pipe are uncemented soils. Closely packed sand and soils which contain large rocks present problems for this method.

As with other pipe-pushing methods, vibratory pipe pushing has straight-hole capability only. This system has been used to make horizontal holes up to 240 ft long with diameters up to 18 in.[41]

Open pipe driven 240 ft was 0.7 ft above grade and 1.9 ft to right of center at the target.[42] Others were less accurate but no figures are available.

Penetration rates by this method are approximately 1 fps; on one job a 12-3/4-in-diam closed-end pipe was driven 58 ft through gravel in 72 sec.[43]

Costs

No data are available on cost per foot of hole. A 1,000-hp Bodine driver costs $75,000.[44] Related equipment such as a crane and trucks may add $100,000 to $150,000 to the equipment costs.

Operating Procedures

A starting pit dug to depth below that at which the pipe is to be driven is usually lined with timber-lagged steel sets to prevent ground from caving in on the equipment set up in the pit. The driver is placed on tracks and alined with transit and level. A snatch block and wire rope is rigged to provide forward thrust for the unit.

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[39] Newfarmer, L. R. Progress of Research on Sonic Methods and Equipment for Underground Utility Installation. 1966 IEEE Tech. Conf. on Underground Distribution, Sept. 28, 1966, pp. 379-403.

[40] Barkan, D. D. Foundation Engineering and Drilling, by the Vibration Method. 4th Internat. Conf. on Soil Mechanics & Foundation Eng., London, v. 2, 1957, pp. 3-7.

[41] Page 386 of work cited in footnote 39.

[42] Page 387 of work cited in footnote 39.

[43] Page 386 of work cited in footnote 39.

[44] Page 390 of work cited in footnote 39.

As the pipe penetrates the soil, extra lengths are added as needed. If open-end pipe is used the spoil is removed with water.

The original alinement is the only control of pipe direction. The pipe itself provides continuous support for the hole.

Equipment

Equipment shown in figure 36 includes a resonant vibrator powered by two 500-hp gasoline engines. No special drilling accessories are required since the pipe itself forms the bit, drill string, and casing.

ROCK PENETRATING METHODS AND EQUIPMENT

The term "rock" as used in this report is defined as the material that forms the essential part of the earth's solid crust; it includes such varieties as granite, sandstone, limestone, and shale.

Diamond Drilling

Diamond drilling is a rotary drilling method using a diamond-studded bit coupled to a string of hollow rods. The drill string transmits torque to the bit and provides a path for the flushing medium. As the bit is rotated and forced against the rock, air or water is pumped down the drill string to flush the rock chips out of the hole.

Two basic types of diamond drilling are coring and noncoring. The coring bit cuts out a central core of rock which is periodically removed by means of a core barrel as the hole progresses. The noncoring bit cuts a full-sized hole without obtaining a core. A picture of a small diamond drill is shown in figure 37.

Drilling Capabilities

Diamond drilling is applicable to all rock formations although some difficulty may be encountered in faulted or blocky material.

Although the diamond drill is primarily a straight-hole tool, use of special wedges permits drilling curved holes.

Diamond-drilled horizontal holes vary in length from a few feet to thousands of feet, and most of these long holes are usually less than 3 in in diameter. Although principally a tool for drilling vertical holes, the diamond drill has been used to drill horizontal holes up to 2,500 ft or more in length.

When the drill is accurately alined and good drilling practices are employed, excellent accuracy may be achieved. In one operation a horizontal hole 704 ft in length was less than 1° off in its entire length[45] while in

[45]Qvale, R. B. The Special Drilling Techniques and Equipment Developed and Used for Drilling Associated with Underground Testing of Atomic Devices at the Nevada Test Site. Proc. 9th Ann. Drilling Symp., Pennsylvania State Univ., 1959, pp. 115-118.

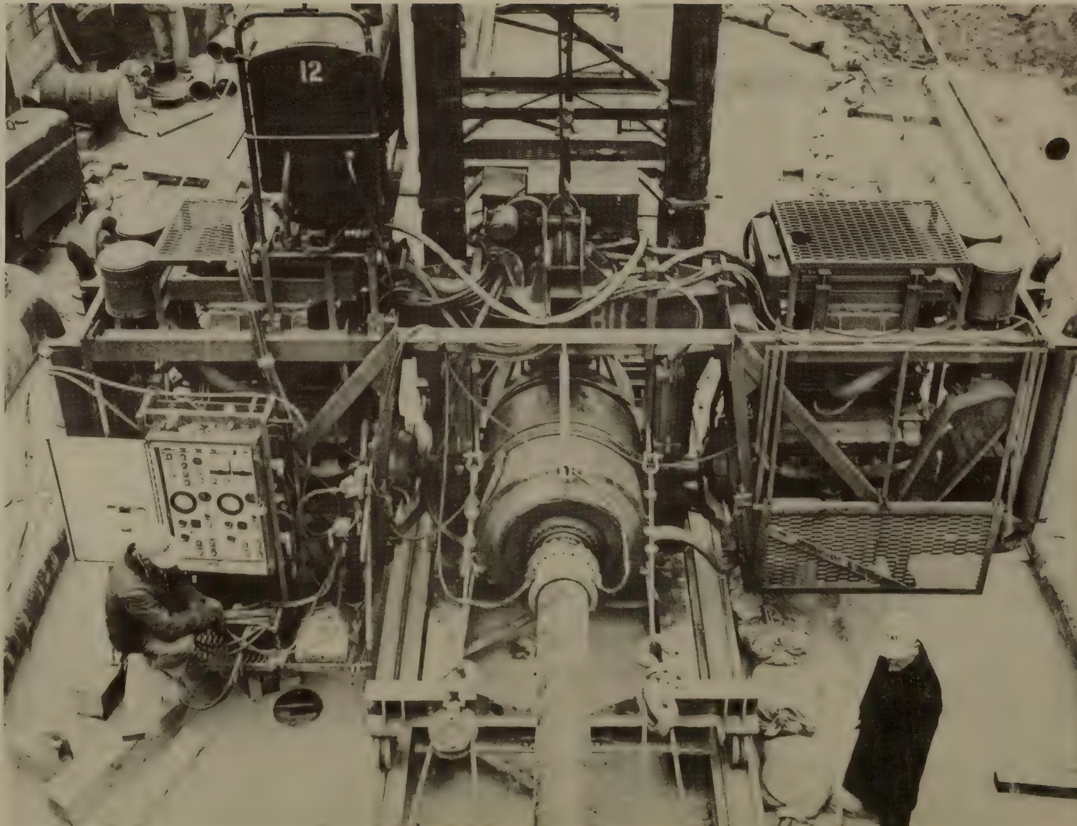

FIGURE 36. - Power Head of Resonant-Vibratory Conduit Driver. *(Courtesy, SoniCo Inc.)*

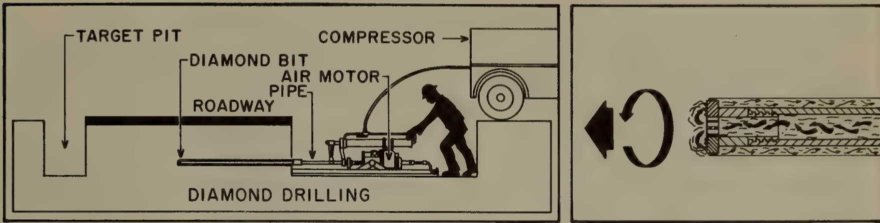

FIGURE 37. - Diamond Core-Drilling Method.

another the deviation was only 0.5° in 2,000 ft. However, in routine drilling without special care, the deviation may range from 2° to 20°.

Penetration rates vary widely with equipment, operating variables, and rock type (table 7).[46]

TABLE 7. - Diamond core-drilling penetration rates in various rocks

Rock type	Location	Compressive strength, psi	Range of diamond drilling rates, ipm[1]	
			1,000-lb thrust	2,000-lb thrust
Granite	Warman, Minn.	22,000	1.7- 4.0	4.0- 5.3
Taconite	Mt. Iron, Minn.	46,100	.1- 2.3	1.9- 7.6
Do	Babbitt, Minn.	49,069	.2- 2.8	.8- 2.5
Do	Aurora, Minn.	64,205	.1- 1.3	.8- 1.6
Trap	Tofte, Minn.	9,800	2.6- 5.3	3.9- 8.9
Anorthosite	do	17,600	2.1- 6.5	.5- 6.4
Gabbro	Gary, Minn.	29,800	3.9- 7.2	5.4-10.6
Dolomite	Mankato, Minn.	10,500	6.3-16.0	9.4-23.6
Quartzite	New Ulm, Minn.	40,000	1.3- 3.9	1.3- 6.5
Granite	Rockville, Minn.	19,200	3.0- 4.1	2.6- 4.3
Do	St. Cloud, Minn.	32,000	2.1- 3.6	2.4- 4.3
Marble	Grandview, Wis.	26,200	1.3- 7.3	5.4-14.2
Do	do	24,700	3.6- 5.8	5.1-10.4
Gabbro	Mellon, Wis.	25,300	2.4- 3.0	3.3- 9.4
Argillite	Wausau, Wis.	28,400	1.4- 1.8	2.7- 5.8
Basalt	Dresser, Wis.	44,500	3.2- 6.0	5.0-14.0
Iron Ore	Humboldt, Mich.	26,900	.3- 1.9	1.5- 5.3
Dolomite	Randville, Mich.	21,700	3.9- 9.5	7.8-17.6
Pegmatite	do	19,300	1.5- 3.4	.6- 2.9
Hornblende schist	do	26,800	2.7- 3.8	3.2- 9.3

[1]Rates were for AX-surface-set bits used at 600, 1,100, and 1,600 rpm.

[46]Paone, James, William E. Bruce, and Pauline R. Virciglio. Drillability Studies--Statistical Regression Analysis of Diamond Drilling. BuMines Rept. of Inv. 6880, 1966, 29 pp.

Costs

The cost of a diamond-drill rig (table 8) depends primarily on the diameter and length of hole it is capable of drilling.[47]

TABLE 8. - Cost of diamond-drill rigs

Hole diameter, in	Depth, ft	Cost, dollars
1-1/4............	250	3,000
1-3/4............	350	3,200
2-3/8............	700	4,000
2-1/2............	750	4,500

Cost per foot of hole varies from $1.80 to $25, depending on rock type. Typical cost per foot of diamond-drilled hole are given in table 9.[48]

TABLE 9. - Core drilling with diamond bits, prices per foot, 1958[1]

Depth, ft	Conventional	Air medium	AX to NX wire line	Pilot-type bit
0- 500	$1.80-$4.00	$1.75-$4.00	$1.75-$5.00	$15.00-$20.00
500- 750	4.00- 9.00	4.00- 8.00	4.00- 5.50	17.00- 25.00
750-1,000	7.00-12.00	7.00-12.00	5.00- 7.00	-

[1]2- to 4½-in-diam holes.

Operating Procedures

Horizontal diamond-drilling operations usually are conducted from a pit dug slightly deeper than the depth of the hole to be drilled. The drill is alined with a level and transit and firmly anchored in position. The first 10 ft length of hole is very carefully drilled and cased to provide a secure and accurate starting point.

As the bit advances in the rock, the resulting rock dust and chips are washed out of the hole with air, water, or mud. The flushing medium is pumped down the center of the drill rods to the bit where it picks up the rock debris and carries it back out of the hole through the annular space between the drill rod and the rock. New lengths of drill rod are threaded onto the drill string as the hole progresses.

[47]Department of the Army. Scientific and Technical Applications Forecast--1964--Excavation. Office of the Chief of Research and Development, Washington 25, D.C., p. 1.2.33.

[48]Redmon, D. E. Exploratory Drilling Practices and Costs at Western Uranium Deposits. BuMines Inf. Circ. 7944, 1960, 68 pp.

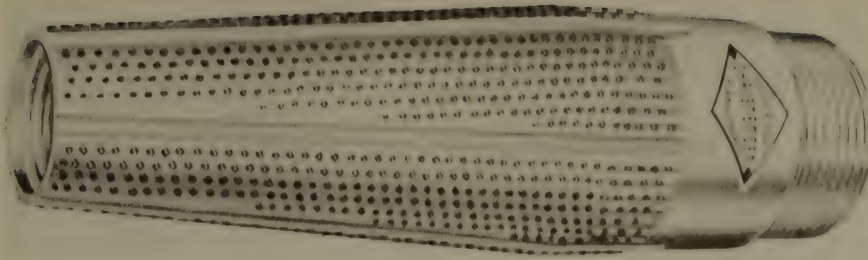

FIGURE 38. - Diamond Reamer. *(Courtesy, Christensen Diamond Products Co.)*

In coring operations the rock core is removed from the hole every 5 to 20 ft, depending on equipment used. When a regular core barrel is used, the entire string of drill rod, including the core barrel, must be removed from the hole to recover the core. A newer method, called a wire-line system, permits recovering a smaller inner core barrel and core up through the drill string without removing the drill string from the hole.

The completed pilot hole can be enlarged with a diamond or rolling-cutter reamer. Each diamond reaming bit usually enlarges the hole to the next largest size; a typical diamond reamer is shown in figure 38.

When drilling loose or caving material, the sides of the hole must be supported to prevent collapse of the hole. Besides serving as a flushing medium, the drilling fluid often provides this necessary support. In extremely loose ground or in a hole which must remain open for a long time, steel casing is usually installed.

Control over the direction of the drill hole depends on either drilling techniques or special wedging devices. Drilling techniques are normally used to prevent deviation of the hole while wedges are used to correct for existing deviation. The critical factors in drilling technique are initial alinement of the drill and proper control of the bit feed, rotational speed, and pump pressure. Existing deviation is corrected by wedges or whipstocks which, when properly oriented in the hole, will change the path of the hole in the direction desired.

Equipment

Power to operate a diamond drill is provided by compressed air, electric, gasoline, or diesel engines. A machine with a capacity to drill a 3,000- to 4,000-ft long hole of AX diameter (1-15/16 in) would require 25 to 50 hp. This power is transmitted to the drive gears through a clutch and transmission. A unit of this size would be about 9 ft long, 4 ft wide, 5 ft high, and weigh about 4,000 lb. A typical diamond drill is shown in figure 39.

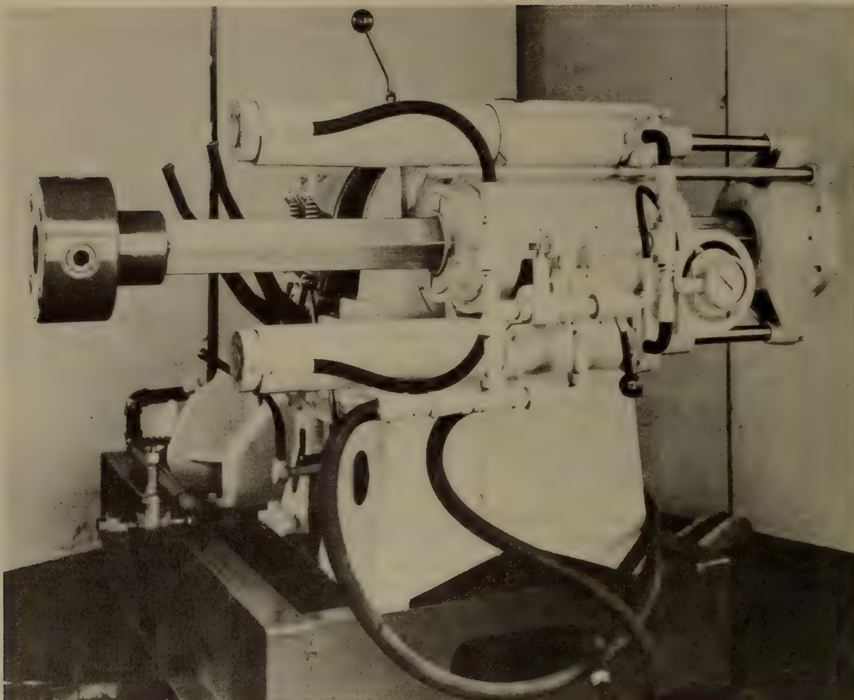

FIGURE 39. - Diamond Drill. *(Courtesy, E. J. Longyear Co.)*

The diamond bit may be coring or noncoring (plug bit) (figs. 40 and 41) and have surface-set or impregnated diamonds. Although in exploratory drilling most bits are of the coring type and are usually of less than 3 in diameter, bits are available in diameter ranging from 1 to 12¼ in.

Drill rods are generally made of carbon steel seamless tubing and are flush coupled. They come in lengths from 1 to 20 ft and in outside diameters from 1-5/16 to 2-3/4 in. Recent trends are to still larger diameter rods.

Rolling-Cutter (Rotary) Drilling

Rotary drilling with rolling-cutter bits is similar to diamond drilling. The rolling-cutter bits are coupled to and rotated by a string of hollow steel rods. Torque is transmitted to the bit by the drill string while air, water, or mud is pumped through the drill rods to remove the cuttings from the hole (fig. 42). A major difference between diamond rotary and rolling-cutter rotary drilling is that rolling-cutter rotary drilling requires double

FIGURE 40. - Diamond Core Bit.
(Courtesy, Christensen Diamond Products Co.)

FIGURE 41. - Diamond Noncoring Bit.
(Courtesy, Christensen Diamond Products Co.)

the weight on the bit and about half the rotational speed to achieve equal rates of penetration.[49] Typical drilling equipment currently available for rotary horizontal drilling are usually heavy-duty diamond-drilling machines or specially constructed machines built exclusively for horizontal drilling.

Drilling Capabilities

This method is used to drill soft to very hard rock. In very soft formations augers and drag bits may be more economical because of their greater rates of penetration.

Although rotary drilling is usually a straight-hole operation, curved hole capability can be achieved when special directional equipment is used.

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[49] Page 1.2.20 of work cited in footnote 47.

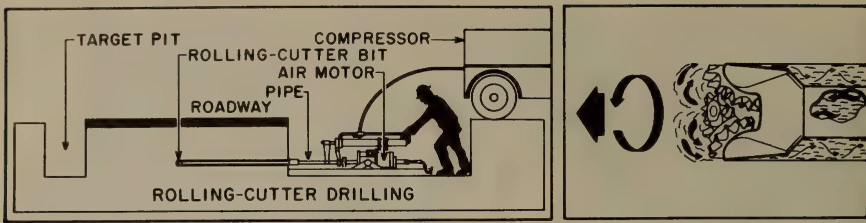

FIGURE 42. - Rolling-Cutter Method.

Large-diameter horizontal holes (33 in) have been drilled to a length of 418 ft;[50] smaller diameter holes could probably be drilled to much greater lengths.

Holes can be drilled in diameters ranging from 3-3/4 to 26 in with a single bit; if several bits are mounted on a common cutting head, holes can be drilled in excess of 36 in.[51] Small pilot holes can also be reamed to larger diameters.

No conclusive evidence is available on the accuracy of this method, but many contractors using specially built drilling machines have had no difficulty in hitting their targets.

Penetration rates vary widely with rock drilled, size of hole, characteristics of the machine, etc., but in general, rates in soft material vary from 40 to 1,000 fph and in very hard formations from 2 to 8 fph.[52]

Costs

Cost, like penetration rate, varies greatly with rock drilled, size of hole, type of equipment, location, but in general, cost ranges from \$0.70 to \$6.00 per ft (table 10) for 3- to 6-in-diam holes.[53]

TABLE 10. - Contract rotary-drilling cost, 1958[1]

Depth, ft	Cost per foot (air and/or water medium)
0- 500..............	[2] \$0.70-\$2.25
500-1,000..............	[2] 1.60- 5.00
1,000-2,000..............	2.50- 6.00

[1] 3- to 6½-in-diam holes.

[2] Price range reflects increased charges when noncore drilling is to be followed by core drilling.

[50] Trent, Thomas R. Horizontal Boring for Subsurface Utility Installations. Pennsylvania State Univ., Min. Ind. Exp. Sta., Bull. 72, March 1960, p. 69.

[51] Page 1.2.10 of work cited in footnote 47.

[52] Page 1.2.11 of work cited in footnote 47.

[53] Work cited in footnote 48.

Operating Procedures

The preliminary setup and actual drilling procedures are similar to those for diamond drilling.

After a pilot hole has been drilled, it can be reamed to a larger size with reaming bits. Reamers may consist of a single bit or a cluster of bits mounted on a single head and they may do the job in one pass or they may take several passes. Although reamers can be either pushed or pulled through the pilot hole, reaming in tension (pulling) usually gives a straighter hole.

In loose or caving formations the hole may require support to prevent its collapse. The pressure of the drilling mud will support the hole in some formations, while in others drilling with air will give the best results. Installing steel casing will of course keep the hole open permanently, or the casing may be used only as a temporary support and later removed. If the cutting heads are mounted on the steel casing itself, the casing serves as the drill string and also provides continuous support for the hole as it is being drilled.

Several special devices can be used to provide directional control over the drill bit. This control is necessary to correct deviation or to intentionally drill a curved hole. These devices including whipstocks, knuckle-joints, special bits, drill collars, etc., are described later in the report in the section on Borehole Survey and Guidance.

Equipment

Smaller, non-oilwell-type rotary rigs are adaptations of diamond drills, and often the same rig can drill with either a diamond bit or a rotary bit.

Rolling-cutter bits range in size from 1 to 26 in in diameter and are constructed with 2 or 3 rolling cutters, each carrying many individual teeth. The construction of the teeth and their arrangement vary with the type of rock being drilled. For drilling in very hard rock, the teeth are replaced with tungsten carbide buttons. The construction of a typical tricone bit is shown in figure 43 and a tungsten carbide bit used for very hard rock drilling is shown in figure 44.

The pilot hole can be enlarged by reaming the hole with special hole-opening tools. These reaming tools utilize rolling-cutter bits mounted concentrically around a guide to prevent the reamer from deviating from the original hole. Cutters are sometimes arranged in Christmas-tree fashion to allow the hole to be reamed to a large size in a single pass. Some typical reamers are shown in figure 45.

Drag-Bit Drilling

Drag-bit drilling has already been discussed under Water Boring and Soil Penetration Methods. The techniques and operation used in rock drilling are similar to water boring or to rotary or diamond drilling as well and will not be discussed here.

DESIGN OF ROTARY DRILLING BITS

TERMINOLOGY OF ROCK BIT ELEMENTS

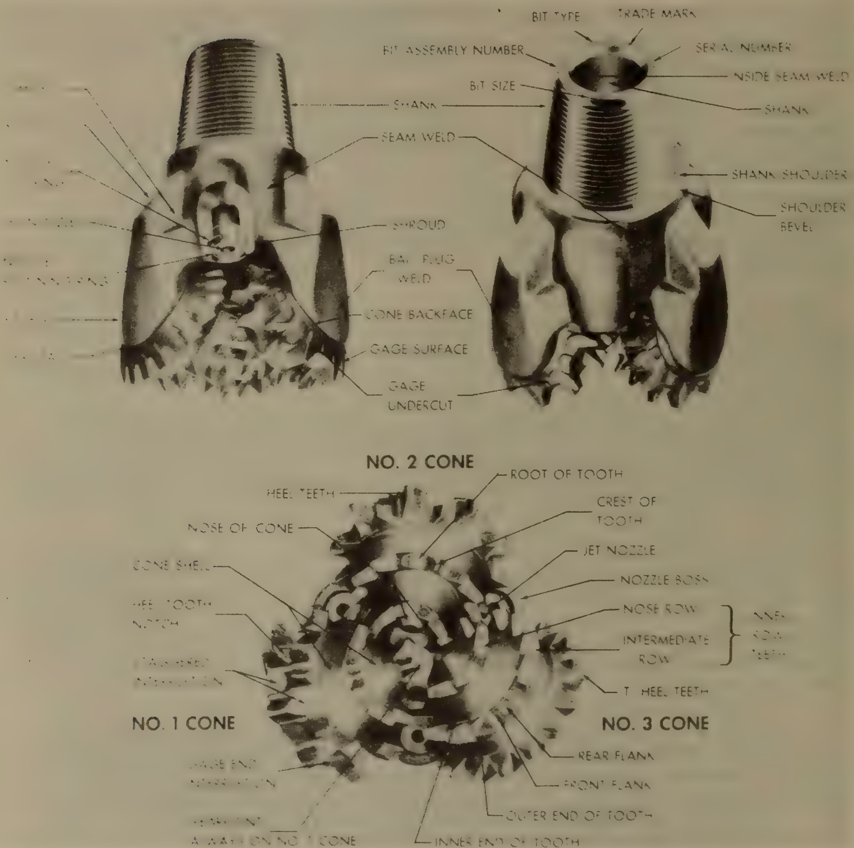

FIGURE 43. - Typical Tricone Bit. *(Courtesy, Hughes Tool Co., Oil Tool Division.)*

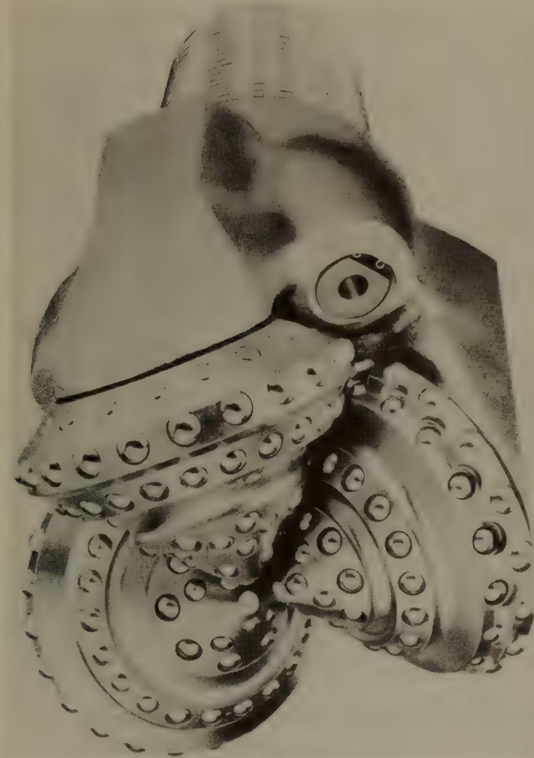

FIGURE 44. - Hard-Rock Tricone Bit.
(Courtesy, Hughes Tool Co., Oil Tool Division.)

Drag bits are used extensively for blasthole and exploratory drilling in the mining industry, but they are limited to drilling small-diameter holes (of only a few inches) in soft formations (salt, coal, potash, etc.). In these soft formations drag bits can drill faster than rolling-cutter bits, although they require about 50 percent more torque than rolling-cutter bits. The larger torque requirement increases the possibility of getting a crooked hole and also the likelihood of drill string failures.[54]

The drilling machines and associated equipment used in rolling-cutter or diamond drilling are also applicable to drag-bit drilling. Drag-bit drilling machines, however, would require twice the rotary speed and 50 percent more torque than rolling-cutter machines.[55] Drag bits are constructed of two or more cutting blades which are usually hard faced to increase bit life (fig. 46).

Specific knowledge is lacking on long horizontal holes drilled with drag bits, but in general they probably have the same capabilities and limitations as augers.

Percussive Drilling

A percussive drill is essentially a hammer and chisel tool. The chisel bit is rotated and simultaneously rapidly impacted by an air-driven piston to fracture the rock. Air is forced down the hollow drill steel to blow the rock debris out of the hole.

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[54] Page 1.2.28 of work cited in footnote 47.
[55] Page 1.2.31 of work cited in footnote 47.

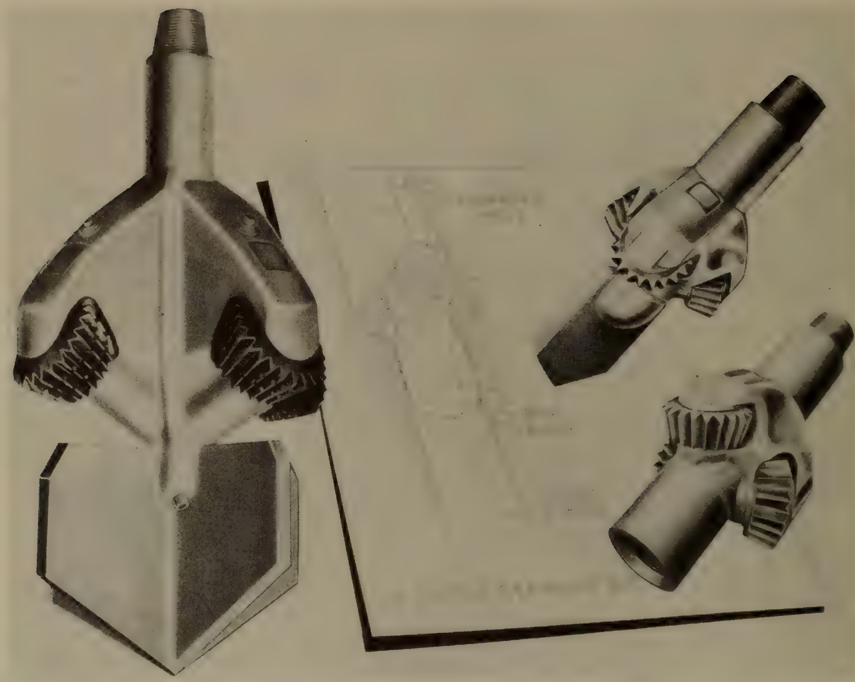


FIGURE 45. - Rotary Drill Reamer. *(Courtesy, Chicago Pneumatic Tool Co., Oil Tool Division.)*

Percussive drills fall into two main groups, those in which the hammer remains at the surface and those in which the hammer follows the bit down the hole. Down-the-hole tools are more efficient, especially for long-hole drilling, because the blow energy is not dissipated in the long drill string. While some horizontal holes have been drilled with this tool, insufficient data are available for accurately assessing the capabilities of the down-the-hole tool. Although down-the-hole hammers may have potential in horizontal drilling, this section will deal only with the surface hammers (fig. 47).

Drilling Capabilities

Although percussive drills can drill most rocks, they may be more economical to use in harder rock since rotary machine bits or drag bits may drill faster in softer rock.

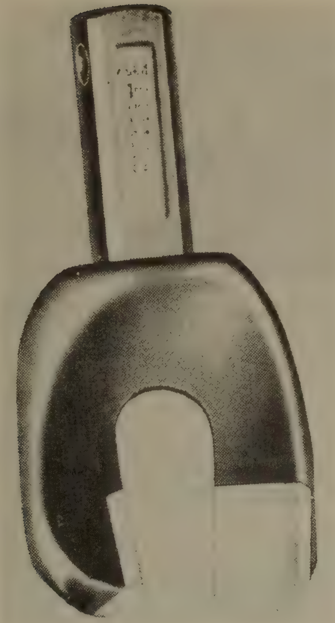


FIGURE 46. - Drag Bit. *(Courtesy, The Salem Tool Co.)*

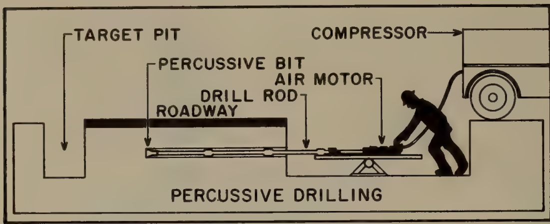
Percussive drills have straight-hole capability only and can drill horizontal holes up to 460 ft[56] in length although maximum lengths of 200 to 300 ft are more common.

Pilot holes have been drilled up to 6 in in diameter but the longer holes are usually less than 3 in in diameter. The pilot holes can be reamed to a larger size with reaming bits.

The best possible accuracy obtainable in vertical drilling with the percussive drill is 0.5 percent deviation with a spread of about ±0.3 percent.[57]

This error would amount to 0.2- to 0.8-ft deviation in a 100-ft hole. However, in horizontal percussive drilling somewhat greater deviation should be expected. Under normal operating conditions, using guide tubes, a minimum deviation of 2 percent should be expected.

[56] Silman, Jack F. Longhole Drilling Vital in Proving Up Molybdenum Corp's Questa Orebody. Min. Eng., v. 17, No. 5, May 1965, p. 55.
[57] Caspar, H. Jörgen. Precision Long-Hole Drilling Applied to Raise-Driving. Sandvik Coromant Tech. Rept. 6401, November 1964, p. 11.



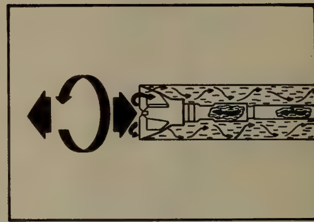


FIGURE 47. - Percussive Drilling Method.

Instantaneous penetration rates to be expected are between 1 and 7 fpm or more depending on rock, size of hole, and condition of drill and bit. In one case the maximum footage drilled by one crew in a 10½-hr shift was 620 ft.[59]

Costs

Percussive drilling cost varies, but in one operation it averaged $1.65 per foot for surface operations to $4.00 per foot underground. These costs are based on 3- to 5-in-diam holes most of which were over 100 ft long.[59]

Operating Procedures

The drill is usually mounted on cylindrical columns within a suitable pit and alined with a level or transit. As the bit penetrates rock, the chips or cuttings are blown out of the hole by either air or water. New lengths of drill rod are added as necessary during the drilling process. Bits must be maintained at proper gage diameter or the bit may become wedged in the hole. In medium to hard ground, multiple-use tungsten carbide bits have a life of 100 to 1,000 ft of hole with 2 to 10 sharpenings, depending on the abrasiveness of the rock.[60]

The pilot hole may be enlarged by attaching a reaming bit and redrilling the hole. A 2-in diam pilot hole can be reamed to 5 in or more and a 2½- to 3-in pilot hole can be reamed to a diameter of 6 in or more.

Accurate drilling of a borehole requires careful initial alinement, good drilling practice, and the use of guide tubes. These guide tubes are nonrotating sleeves which fit over the drill steel and seat snugly in the drill hole to prevent the smaller diameter drill rods from bending. These tubes are slotted to allow the cuttings to pass over them and out of the hole.

Since the percussive drill is used in rock, normally no support of the hole is necessary. If any is called for, casing can be installed to insure a permanent opening. In some instances fuel oil can be injected into the air stream to condition the hole and reduce its tendency to cave.

[58]Page 57 of work cited in footnote 56.
[59]Pages 57, 58 of work cited in footnote 56.
[60]Page 1.3.20 of work cited in footnote 47.

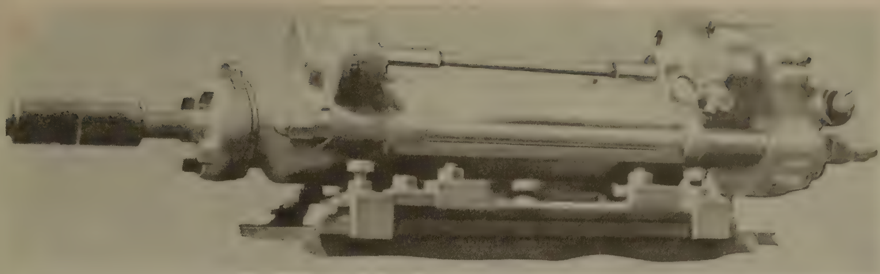


FIGURE 48. - Percussive Drill With Independent Rotation. *(Courtesy, Gardner-Denver Co.)*

Equipment

The $3\frac{1}{2}$- to 5-in air-powered percussive drill operating at 90 to 100 psi requires from 180 to 400 cfm of air, depending on the type of drill. In general the drill should have a cylinder bore at least 1 in greater than the diameter of the hole drilled.[61] A typical independent-rotation percussive drill is shown in figure 48. A drill of this type requires 550 to 600 cfm at 90 to 100 psi.

Drill bits are available in diameters ranging from 1 to 6 in and usually consist of a four-element cutter design arranged in a cross-shaped pattern. Most modern bits use tungsten carbide inserts to increase cutting efficiency and can be resharpened one to 10 times. A typical tungsten carbide drill bit is shown in figure 49.

Reaming bits usually have a short pilot adapter which follows the pilot hole and prevents deviation from it. The cutting elements are similar in design to those of percussive drill bits.

Drill rods range from 7/8 to 2 in in diameter and from 1 to 30 ft in length. They are made of high-grade alloy steel and are threaded on each end for coupling.

Control equipment usually consist of guide tubes (fig. 50) which fit around the drill rods and have an outside diameter slightly less than that of the drill hole. They are slotted to allow passage of the rock chips.

Machine Tunneling

Tunnel-boring machines are of diameters in excess of the 36-in size limit which is generally the largest size used for underground power transmission lines. Some existing machines approximate this size sufficiently to merit a discussion on machine boring.

[61] Page 1.3.22 of work cited in footnote 47.

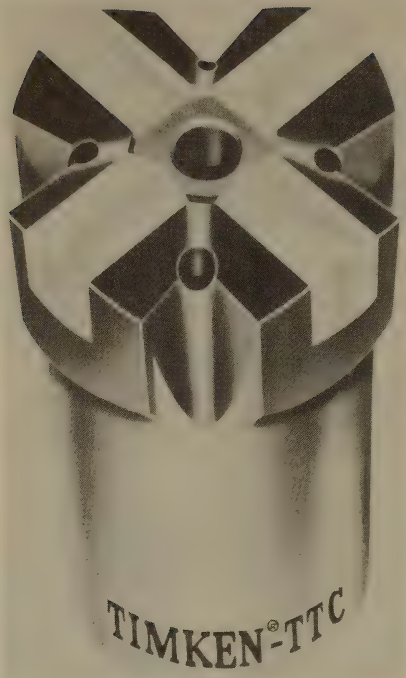


FIGURE 49.- Tapered-Socket Bit With Tungsten Carbide Inserts. *(Courtesy, Timken Roller Bearing Co., Rock Bit Division, Colorado Springs, Colo.)*

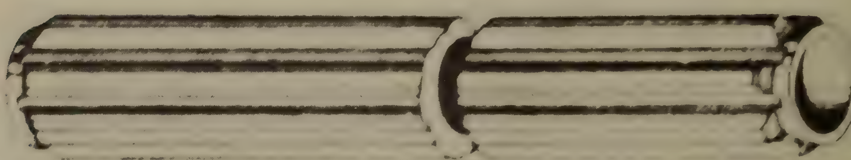


FIGURE 50. - Guide Tube for Percussive Drilling. *(Courtesy, Gardner-Denver Co.)*

Boring Capabilities

Tunneling machines have capability of boring through a wide variety of rock. Present state of the art could immediately provide holes of about 5½ ft in diameter or larger. In 1958 and 1959 the Hughes Tool Co. designed and manufactured a 40-in-diam tunneling machine (fig. 51) to be used as a

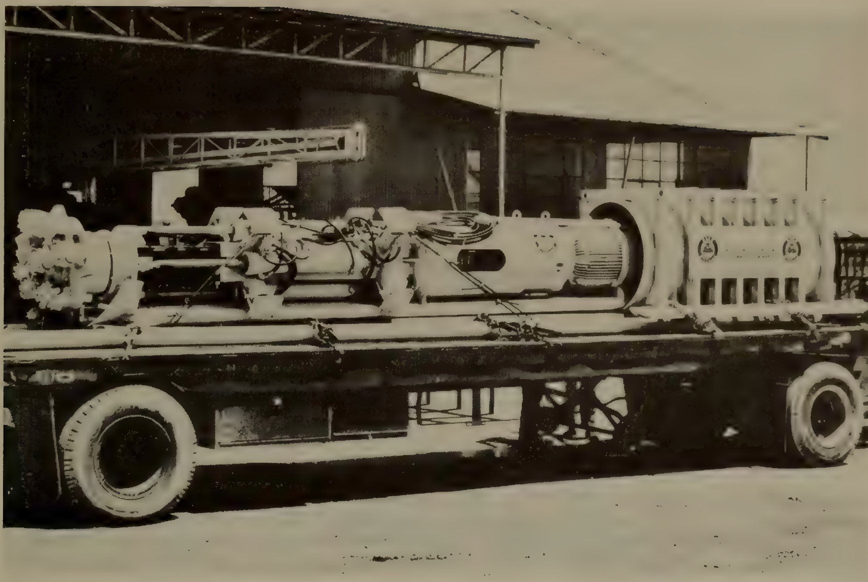


FIGURE 51. - Forty-Inch-Diameter Boring Machine. *(Courtesy, Hughes Tool Co.)*

laboratory tool in evaluating requirements and feasibility of applying boring machines to hard rock. Some of the machine characteristics and capabilities are as follows:

Weight....................pounds..	15,000
Length.....................feet..	27
Horsepower.......................	75
Rotational speed.............rpm..	16.5
Anchoring force...........pounds..	313,000
Thrust.....................do....	226,000
Stroke...................inches..	30

Tests with this machine in a Texas granite quarry containing rocks of 40,000 psi compressive strength yielded advance rates of 1-3/10 fph. Advance rates of 8½ fph were obtained in 14,000 psi limestone in a British quarry. Since in these tests only short runs were made into the quarry walls, guidance was not a problem.

In 1961 the 40-in machine was modified to 54-in diameter for use by the American Gilsonite Co., Bonanza, Utah, in their gilsonite mines. Early tests at the mine site brought out problems related to the control of direction and the negotiation of curves. The machine was again modified by

sectioning it into two units and adding auxiliary jacks for alining the machine during the reset or retraction portion of the operating cycle.

Since the absolute control of line and grade in this mining operation was not of major concern, the techniques utilized were adequate under the circumstances. The machine was made to follow a seam of gilsonite rather than a predetermined line and difficulty was encountered only when curve radii of less than 250 ft had to be negotiated. More difficulty was experienced with the maintenance of grade than with line.

The experience gained with the 40- to 54-in machine pointed out some problems associated with maintaining the directional control of such a tunnel-boring machine. It was concluded that correction in alinement had to be made during the boring stroke and that the operator had to have constant visual recognition of the machine position in relation to the projected line and grade. This experience was applied to the design and development of the successful and much publicized 18-ft-diam "Betti I" in 1964 and a laser-beam directional-control device was incorporated which permitted boring to within 5/8 in of projected line and grade by providing the operator with a constant visual indication of position relative to line and grade.[62]

At the American Gilsonite Co., Bonanza, Utah, operation the tunnel borer was guided by one man at the rear of the machine. It was thought possible to develop a remote control guidance system employing television cameras and other equipment. The tunnel borer was able to penetrate rock at 5 fph and gilsonite at up to 20 fph.[63]

Costs

Available information indicates that a rule of thumb for the first cost of tunnel boring machines is about $1,000 per horsepower in the 8- to 20-ft-diam range.[64] Antonides, however, reports that the cost of the tunneling machine can be estimated as $750 to $800 per horsepower in the 10- to 20-ft-diam range. He also gives formulae for the estimation of total time for tunneling and total cost of tunneling.[65]

Five case histories, courtesy of the Calweld Division of Smith Industries International, Inc., are summarized in table 11.

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[62] Information courtesy of Hughes Tool Company, Industrial Products Division, Dallas, Tex.

[63] Engineering and Mining Journal. Tunnel Borer and Shaft Drill Teamed at AGC's Hydraulic Mining Operation. V. 164, No. 7, July 1964, pp. 69-70.

[64] Norman, N. E., and R. Stier. Economic Factors of Mechanical Rock Tunneling. Min. Eng., v. 19, No. 6, June 1967, pp. 75-78.

[65] Antonides, Lloyd E. Potential for Tunnel Boring Machines, Nevada Test Site (Revised). U.S. Atomic Energy Commission, Nevada Operations Office, Las Vegas, Nev., March 1966, 52 pp.

TABLE 11. - Costs for soft-ground boring

Contractor	S. A. Healy Co.	Kenny Construction Co.	Kenny Construction Co.	George Hardin Construction Co.	S. A. Healy Co.
Location	Chicago	Chicago	Chicago	Chicago	Chicago
Tunnel length...feet	18,000	12,000	3,500 and 2,000	5,875	8,000
Diameter...do	9	9	7.5	11.33	19
Average advance rate..feet per hour	8.00	6.25	7.50	6.00	5.50
Maximum advance rate...do	13	-	-	7.55	17.5
Cost per foot	$4.44	$7.33	$8.90	$11.00	-
Cost per cubic yard	$1.88	$3.12	$5.46	$2.92	-
Cutter costs per foot	$0.60	$0.65	$0.99	$0.30	$3.08
Maintenance cost per foot	$0.45	$0.48	$0.65	$0.57	$5.02
Power costs per cubic yard	$0.045	$0.09	$0.09	$0.48	$0.28
Operator and oiler costs per foot	$1.50	$1.92	$1.60	-	-
Total operating costs per foot (machine only)	$7.10	$10.59	$12.23	$14.35	About $11.80
Total time for job...months	12	8	9	9	9
Material excavated	([4])	([4])	([4] [5])	([4])	([4])
Prime mover type	671GM Diesel	Electrohydraulic	Electrohydraulic	Electrohydraulic	-
Horsepower	142	100	-	160	-

[1] Based on complete machine amortization at job completion.
[2] This was fuel cost for a diesel engine.
[3] Generated their own power with diesel engine driving Delco 200-kw generator.
[4] Clay with gravel, boulders, sand, and water.
[5] Rock was encountered which was broken conventionally.

BOREHOLE SURVEY AND GUIDANCE

Survey of Boreholes

In order to determine the exact position of a borehole, a borehole survey must be made to determine the position of the hole with respect to the horizontal (inclination) and with respect to north or another fixed reference (direction). The depth or length of the borehole can be determined simply by measuring the length of drill rod in the hole. Surveys may be taken at a single point in the hole or at intervals along the length of the hole depending on what information is required.

Borehole survey instruments are of three kinds: (1) Inclinometers for recording inclination only; (2) directional devices for recording the direction only; and (3) combination devices for recording both inclination and direction. If the device can produce only one reading per survey, it is called a single shot and if it can produce multiple readings per survey, it is called a multishot instrument.

Inclination Devices

Regardless of the sophistication of the associated recording device or packaging, all inclination measuring devices rely on the force of gravity to maintain a fixed reference. The difference between the fixed reference and the changing axis of the borehole is then recorded as the measure of inclination.

Etch Tube

The etch tube inclination device relies on the fact that the free surface of a liquid at rest will always remain level or horizontal by force of gravity. To measure the deviation of a drill hole with an etch tube, a glass bottle partially filled with a solution of hydrofluoric acid and water is lowered into the hole (fig. 52). After 15 to 20 minutes at the desired measuring point, the acid solution etches the glass bottle. The angle between the line at the top of the etched surface and the wall of the bottle represents the deviation of the hole from the horizontal.[66] Because of the etch time, this method is slow and is only accurate to within several degrees.[67] It is, however, inexpensive and can be used in holes with diameters as small as 1 in. Although the method is commonly applied to vertical holes, it is felt that the method is also applicable to horizontal holes.

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[66] Lahee, F. H. Problem of Crooked Holes. Bull Am. Assoc. Petrol. Geol., v. 13, No. 9, 1929, p. 1145.

[67] Uren, Lester Charles. Petroleum Production Engineering. McGraw-Hill Book Co., Inc., New York, 3th ed., 1946, p. 709.

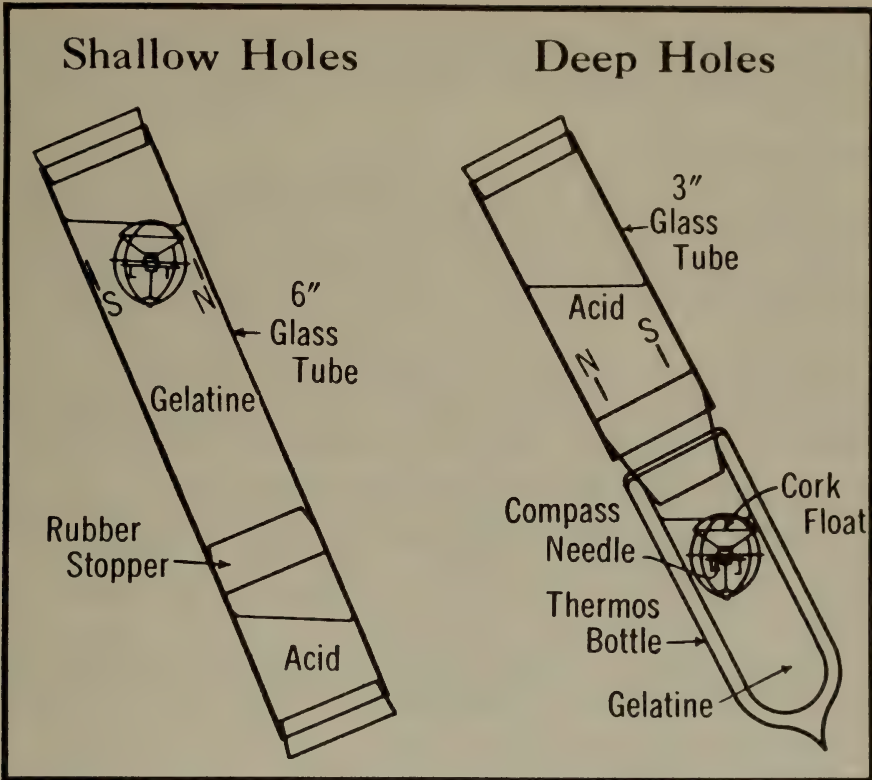

FIGURE 52. - Maas Compass (Magnetic Compass and Etch Tube).
(Courtesy, Sprague & Henwood, Inc.)

Manometer Device

This method[68] of surveying long, rising, horizontal holes by measuring the head of water within the drill rods on a manometer or other pressure gage can be done quickly and is sensitive enough to give an accurate profile of the hole as it is drilled. When a reading is required, the drilling operation stops for only a few minutes while the reading is made. This method is used during drilling operations in coal seams and a disadvantage is that it gives no indication of the position of the borehole relative to roof or floor of

[68]Baxter, J. S. Drilling of Long Boreholes in Coal. Colliery Eng., v. 36, No. 430, December 1959, p. 521.

the coal seam and the pressure will cease to rise if the hole falls below the horizontal, thus providing no further quantitative information until it begins to rise above the horizontal again. This method, where applicable, is simple, inexpensive, and rapid.

Gimbal-Mounted Devices

Because it is free to swing on its mountings, a gimbal-mounted plumb bob will remain in fixed position because of gravity. The gimbal-mounted device then maintains a fixed reference and the gimbal mount, because it is rigidly attached to the protective case, follows the axis of the borehole. To determine the inclination requires devising a scale to indicate the difference between these two axes. One device, the Tro-Pari instrument, uses a time-lock mechanism to lock the gimbal-mounted compass as well as the compass needle in the hole at a preset time.[69] This allows the instrument to be withdrawn from the hole and the reading taken at depth to be observed. This one-shot device is accurate, relatively fast, and is inexpensive to use. Although this inclination sensing device can be used anywhere, the directional compass would be unreliable in the presence of ferromagnetic material.

Pendulum, Float, Bubble-Level Devices (Oil-Well Survey Devices)

These inclinometers are discussed together because they are usually found in complex commercial oil-well survey devices combining a recording device, timer, camera, and light and power sources. These inclinometers can be used in a single-shot device or as a more complex multishot device capable of recording as many as 1,000 readings on a single run.

The inclination of a borehole is determined by recording either the position of a gas bubble on a liquid surface, the position of a float on a liquid surface (sometimes called an inverted pendulum), or the angle of inclination of a pendulum. Plates or spheres with concentric graduations show the vertical inclination in degrees between the fixed reference and the borehole axis.[70] Permanent records are then made of these readings by photographic, chemical, electrical, or mechanical means. Commercial survey devices are fast, accurate, and can be used in holes with a diameter as small as 1 in. The simpler, one-shot device is usually rented by the contractor, but the more complex multishot devices are operated only by trained company personnel.

Directional Devices

Magnetic Compass

Although the simple magnetic compass is the most common method of determining the direction of a borehole, it has the serious drawback of giving

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[69] Cumming, J. D. Diamond Drill Handbook. J. K. Smit & Sons of Canada Ltd., Toronto, Ontario, 1st ed., 1951, pp. 329-332.

[70] Trengove, Russell R., and A. C. Johnson. Sampling Deep Ore Deposits by Rotary Drilling and Methods of Surveying and Controlling the Direction of Drill Holes. BuMines Inf. Circ. 7768, December 1956, pp. 7-15.

unreliable readings in the presence of ferromagnetic objects. It is consequently limited to surveying uncased holes or to a nonferromagnetic environment.[71] The compass, when applicable, must be lowered into the hole with special drill rods of brass or nonmagnetic metals which isolate the device from the rest of the drill string.

The major difference between devices using the compass is the method of recording the compass reading. This record may be made in several ways: Placing an open compass in a container of melted gelatine and waiting for the gelatine to congeal and freeze the compass needle in position; setting a timelock mechanism to lock the needle in position at a predetermined time;[72] applying radioactive paint to the tip of the compass needle to indicate the reading on photographic film;[73] and using a camera and film to photograph the reading at a predetermined time.

In operation the gelatine-setting devices are the slowest, followed by the radioactive method, while the mechanical timelock and photographic methods are fastest. The photographic system is the only available multishot device. The gelatine-setting, mechanical, and radioactive methods call for the least expensive equipment but the gelatine-setting and radioactive methods are also more time consuming to use. Devices using photographic equipment are not sold but can be rented. In the case of the multishot, the equipment is operated only by trained company personnel. All these methods are limited to use in a nonferromagnetic environment and all have about the same degree of accuracy.

Gyro Compass

The gyro compass (fig. 53) is the only commonly used direction-finding device that can be used in a ferromagnetic environment. Consequently, it can be used in cased or uncased holes, in the presence of other ferromagnetic objects, or in the presence of spurious magnetic fields.[74]

Gyro compass survey devices employ an electrically powered gyroscope which has the ability to maintain its axis in whatever plane it may be set. An optical or electrical pickoff device measures the deviation of the borehole from the preset reference axis and a permanent photographic record is then made of this reading.[75] A commercial gyro survey unit will usually contain the gyro compass unit, a timer, camera, light, and power supply and may be built as a single or multishot device.

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[71] Cumming, J. D. Surveying Methods for Small Holes. Proc. 7th Ann. Drilling Symp., Exploration Drilling, Univ. Minnesota, Minneapolis, Minn., Oct. 3-5, 1957, p. 96.

[72] Work cited in footnote 71.

[73] Wright, Lawrence B. Borehole Surveying at the Homestake. Eng. and Min. J., v. 126, No. 2, July 14, 1928, pp. 57-58.

[74] Lower, J. W. Gyro Compass and Possible Adaptation to Surveying of Small Boreholes. Proc. 7th Ann. Drilling Symp., Exploration Drilling, Univ. Minnesota, Minneapolis, Minn., Oct. 3-5, 1957, pp. 100-104.

[75] Page 102 of work cited in footnote 74.

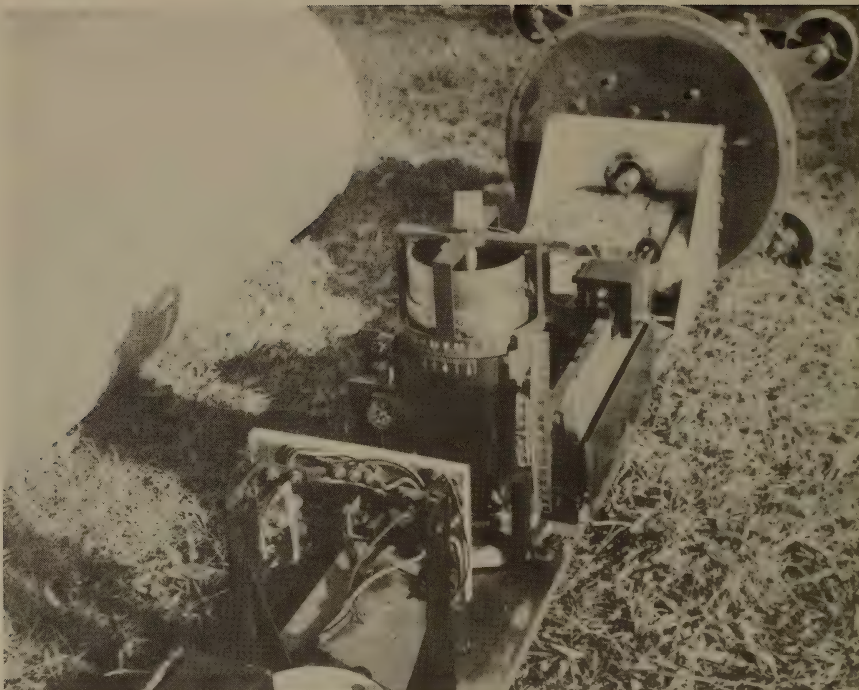

FIGURE 53. - "Mole" Gyroscopic Horizontal-Survey Device.
(Courtesy, Sperry-Sun Well Surveying Co.)

The gyro compass is fast, accurate, and will work in a ferromagnetic environment. The device, however, is currently limited to use in holes with a diameter of 4 in or greater.

Carlson-Bergstrom and Gommesson Methods

Since the Carlson-Bergstrom and Gommesson methods[76] are similar, they will be discussed together. The method in general consists of lowering a rigid tube up to 30 ft in length into the drill hole. Inside this tube is a fine wire under tension which is attached to both ends of the tube. The tube is oriented by transit at the surface and fits the hole snugly. The difference between the arc of the tube and the chord of the wire indicates a change in direction and is recorded in the tube by stylus markings.

[76] Pages 327, 328 of work cited in footnote 69.

Although this method has not been used in this country, it is mentioned because it is the only directional method besides the gyro compass that is not affected by ferromagnetic objects or magnetic fields.

Combination Devices

Combination devices measuring both inclination and direction are usually identified by commercial brand names. The individual inclination and directional devices have been previously described and are summarized in table 12.

TABLE 12. - Borehole-survey devices

Name or type	Inclination	Direction
Carlson compass.............	Gimbal-mounted plumb (compass).	Magnetic compass.
Maas compass................	Etch tube......................	Do.
Wright radiolite compass....	Gimbal-mounted plumb (compass).	Do.
Tro-Pari....................	.....do........................	Do.
Carlson-Bergstrom, Gommesson	Etch tube......................	Arc and chord.
Sperry-Sun's "Mole"[1]........	Pendulum.......................	Gyro compass.
Others (oil well devices)[2]..	Bubble level, float, pendulum..	Magnetic compass.

[1] See figure 53.
[2] See figure 54.

Directional Control (Guidance)

Most of the tools and techniques presented in this section have been developed by the oil industry for use in vertical or near-vertical holes. Although these methods may be applicable to horizontal drilling, their usefulness can be ascertained only after actual field use.

The direction of a drill hole can be controlled either by prevention-of-deviation drilling or by correction-for-deviation drilling. Prevention-of-deviation drilling is the more important technique because correction-for-deviation devices are both costly and time consuming to operate, especially for short holes.

Causes of Drill Hole Deviation

All holes tend to deviate from a true line because of one or more of the following factors: faulty alinement, poor drilling technique, gravity,

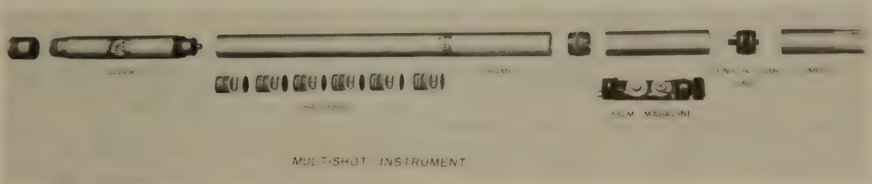

FIGURE 54. - Magnetic Multishot Survey Instrument. *(Courtesy, Sperry-Sun Well Surveying Co.)*

and the nature of the formation itself. One of the most serious causes of errors is faulty alinement because small initial errors are accumulated as the hole advances. These errors can be largely eliminated by an accurate alinement of the drill.[77] Excessive pressure on the bit is another common source of error[78] which causes the drill column to flex until it contacts the wall of the hole. The angle formed by this contact produces an offcenter force which cause the bit to wander. This source of error can also be eliminated by applying less force to the bit and increasing rotary speed.

The weight of a long horizontal drill string itself exerts a force which tends to deflect the hole downward. This error can be reduced by using a stiff nonbending drill assembly and by starting the hole a few degrees above horizontal to allow for the deflection.[79] The last source of error is unpredictable because of such nonhomogeneous features of rock as faults, dip, bedding planes, etc., all of which tend to deflect the drill head.[80] To minimize errors related to these causes, the driller must rely on good drilling practices and use of special drilling devices.

Prevention-of-Deviation Drilling

Tools described separately below are used in combination in actual field use for maximum effect. For instance, stabilizers, reamers, and drill collars combined in various configurations can provide the optimum assembly for minimizing deviation in any particular formation.[81] When used together, proper drilling technique and tools offer maximum protection against drill hole deviation. Some bottom-hole assemblies combining drill collars, stabilizers, and reamers are shown in figure 55.

Drilling Techniques

Drilling technique, one of the most important means of preventing deviation, is hard to define as it is an art depending on the driller's "feel" for what is happening down the drill hole. This art acquired only through experience, accounts for such variables as the proper control of bit pressure, rotary speed, pumping pressure, etc.[82]

Drill-String Stabilizers, Collars, and Reamers

Drill-string stabilizers are slotted rigid sleeves fitting over the drill steel and with an outside diameter slightly less than that of the hole. They are usually placed directly behind the bit and at intervals along the drill string. These stabilizers keep the bit centered and help prevent bending or whipping in the drill string.[83]

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[77] Work cited in footnote 57.

[78] LeVelle, James A. Controlled Directional Drilling. Petrol. Eng., v. 29, No. 11, October 1957, p. B-81.

[79] Page 13 of work cited in footnote 57.

[80] Page 310 of work cited in footnote 69.

[81] Crews, Sam T. Bit Stabilizing Assemblies Control Dog-legs. Drilling, v. 28, No. 7, Apr. 15, 1967, p. 78.

[82] Page 310 of work cited in footnote 69.

[83] Work cited in footnote 78.

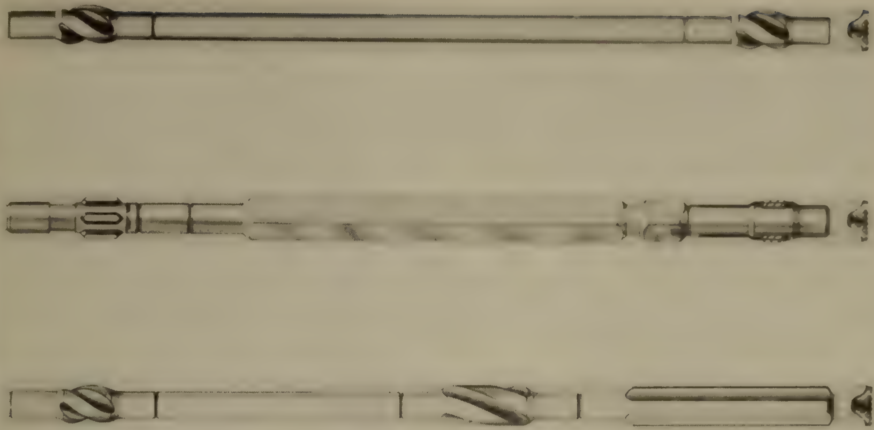

FIGURE 55. - Bottom-Hole Drill Assemblies Combining Reamers, Stabilizers, and Drill Collars.
(Courtesy, Drilco Oil Tools, Inc., Midland, Tex.)

Drill collars are oversize, heavy, and rigid sections of drill string placed directly behind the bit. Collars fit snugly into the drill hole and have a round or square cross section, although square collars are said to be more effective in special instances.[84] These collars work like stabilizers in that they prevent bending and rapid deflection of the drill string.

Reamers sometimes placed behind the bit to keep the hole to gage may contain rolling-cutter blades or diamond-studded blades. Thus they also serve to center the bit much as drill-string stabilizers do.[85] Figure 56 shows some rolling-cutter reamers and their effect on a drill string.

Correction-for-Deviation Drilling

Correction-for-deviation drilling consists of using special directional drilling tools and techniques to correct for existing deviation of the drill hole.

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[84]Allen, R. H. Square Drill Collar Controls Deviation. Oil and Gas J., v. 61, No. 27, July 8, 1963, pp. 124-127.
Rollins, H. M. Controlling Crooked Holes. World Oil, Drilling Sec., v. 142, No. 5, April 1956, pp. 183-186.

[85]Work cited in footnote 78.

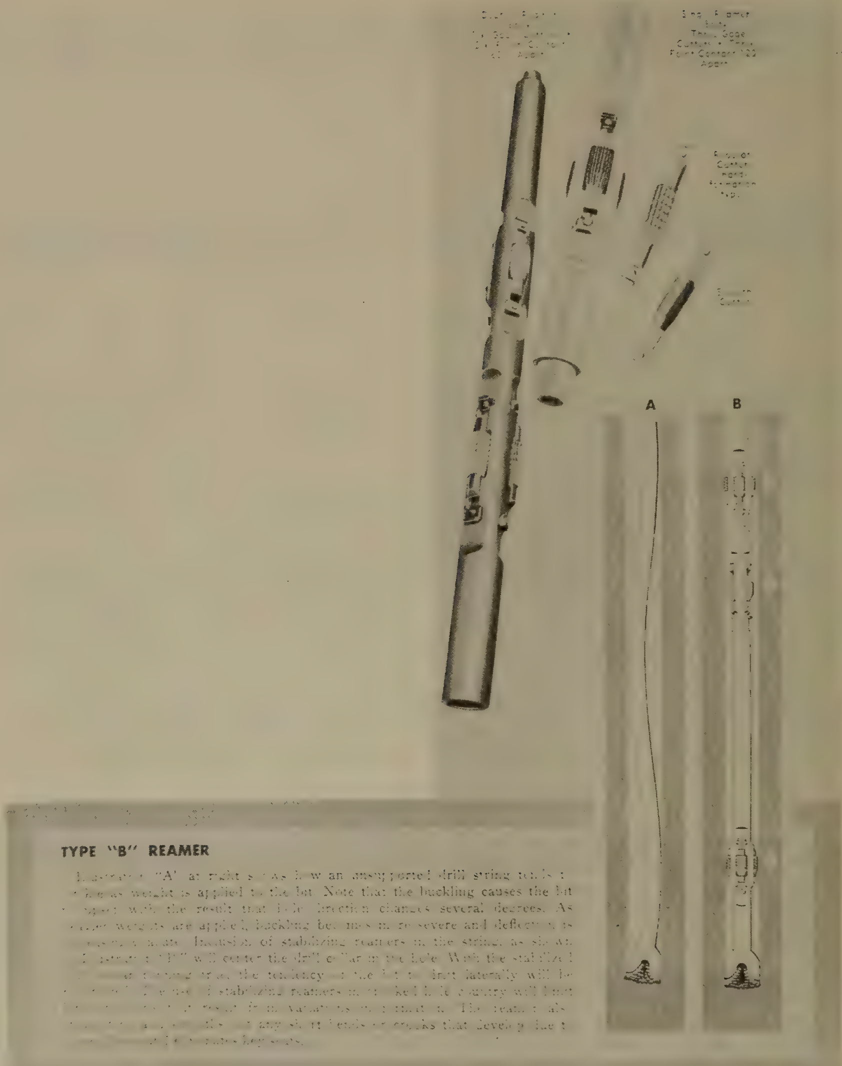
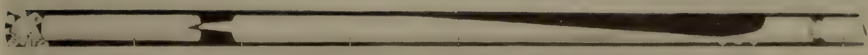


FIGURE 56. - Rolling-Cutter Reamers and the Action of Reamers on a Drill String.
(Courtesy, Chicago Pneumatic Tool Co., Oil Tool Div.)



DEFLECTING WEDGE

SIZE	EX	Wgt.	AX	Wgt.	BX	Wgt.	NX	Wgt.
ASSEMBLY NO.	21090 1	40 LB	21090 2	54 LB.	21090 3	85 LB	21090 4	161 LB

FIGURE 57. - Deflecting Wedge or Whipstock. *(Courtesy, Acker Drill Co., Inc.)*

Whipstocks, Knucklejoints, Special Bits, Reamers, and Bit Boss

A whipstock[86] is a long tapered steel wedge with a concave groove on its inclined face (fig. 57). The inclined face of the wedge, providing a new path for the bit to follow, can be oriented in any direction. Most wedges offer deflections of less than 4°, but more than one wedge can be used in the hole to achieve any desired angle. After the wedge has corrected the deviation, it is removed and conventional drilling is resumed.

Knucklejoints[87] consist of a ball-type universal joint and allow the bit to drill at a predetermined angle to the drill string. When starting, the knucklejoint is maintained at some set angle by a spring-loaded cam, but as the joint enters the newly formed hole, it straightens out and maintains the initial deflection.

The "big-eye" bit[88] has one waterway constructed larger than the others. When a change in direction is required, the rotation stops, the bit is alined, and a high-pressure jet of water washes out part of the hole in the direction the hole is to be deflected. After a pocket has been formed, drilling can continue with the original bit. This method requires large pumps to wash out the hole and can be used only in soft formations.

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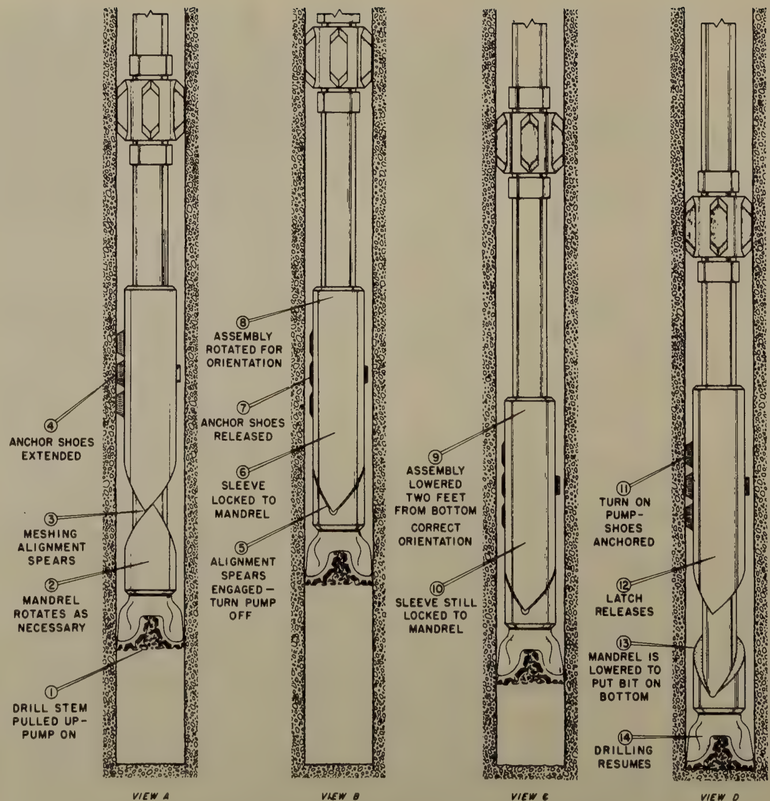
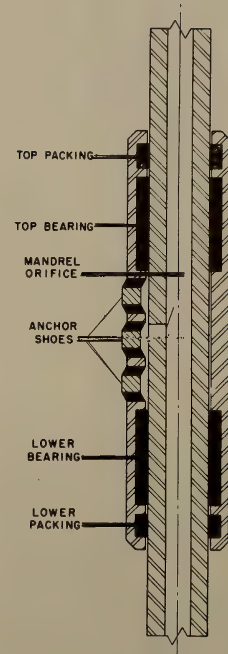
[86] Vanabo, J., and O. Logu. Wedging Diamond Drill Holes by an Improved Method. Eng. and Min. J., v. 165, No. 5, May 1964, pp. 104-105.
Pages B-81, B-83 of work cited in footnote 78.
Pages 371-373 of work cited in footnote 67.

[87] Page 373 of work cited in footnote 67.

[88] Dwyer, Roy P. Jet Deflection--A Recent Advancement in Directional Drilling. Petrol. Eng., v. 31, No. 5, May 1959, pp. B-77 through B-82.
McGhee, Ed. "Big-Eye" Bit Successful in Soft Formations. Here is how Holes are Deviated with Jet Bits. Oil and Gas J., v. 56, No. 27, July 7, 1958, pp. 131, 134.



Operation of the tool (follow numbers in sequence)



Section of assembly showing means of expanding anchor shoes

FIGURE 58. - "Bit Boss" Hydraulic Directional Control Device.

(Courtesy, Drilco Oil Tools, Inc., Midland, Tex.)

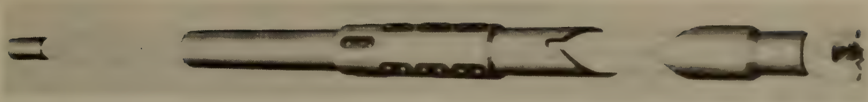


FIGURE 59. - "Bit Boss". *(Courtesy, Drilco Oil Tools, Inc., Midland, Tex.)*

The curlew bit combines jetting and spudding action to form a pocket in the direction the hole is to be directed. After the pocket is formed, the curlew bit is removed and a conventional bit is used to continue drilling in the newly formed pocket. The jetting action of this bit is similar to that of the "big-eye" bit, and is also limited to soft formations.

Reamers[89] are sometimes placed behind the bit to increase the initial angle produced by the deflecting device. These reamers are similar to those used in straight-hole drilling.

The "Bit Boss"[90] is a special bottom-hole tool which uses a set of hydraulically activated shoes for pushing against the walls of the hole and thus providing continuous hole angle control (figs. 58 and 59). The pressure of the drilling fluid activates these shoes to position and lock the anchor sleeve in any desired direction. The mandrel and attached bit slide through this anchor sleeve and begin drilling at the preset angle. The operation of this unit requires drilling fluid under high pressure.

Orientation of Tools

Once the need for a directional control device has been ascertained, usually by a drill hole survey, it must be alined on the bottom of the hole in the proper position. This operation must be accurate, as the misalinement of the tool will deflect the hole in the wrong direction. Alinement is usually effected with one of the commercial one-shot survey devices. These alinement devices are rapid and accurate but also somewhat complicated to use. One of the simplest orientation methods,[91] the orientation of the drill rods themselves, is inexpensive and has good accuracy for short holes. Essentially the position of the tool with respect to the drill rods is kept intact as each new section of drill pipe is added onto the drill string. Since the position of the tool bears a fixed relationship to the rods, its orientation in the hole can be determined simply by observing the orientation of the drill rods.

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[89] Work cited in footnote 78.

[90] Cheatham, J. B., Jr. A Method for Controlling Hole Inclination and Direction. Pres. at Petroleum Mechanical Engineering Conf., New Orleans, La., Sept. 10-21, 1966.
Garrett, W. R., and H. M. Rollins. New Tool Steers Drill Bit. Oil and Gas J., v. 62, No. 5, Nov. 9, 1964, pp. 194-196, 199.

[91] Page 363 of work cited in footnote 69.

OBSTACLE DETECTION

Locating obstacles in the path of a projected borehole is important particularly in highly populated areas likely to have many underground structures and utilities. Ignorance of these obstacles during boring operations could result in hazards to personnel and damage to an existing utility.

Many detection devices detect an injected signal or magnetic field emanating from a buried cable;[92] proximity to other utility pipes and cables as might be found under a city street, would probably distort the signal, rendering the results inaccurate.[93] Most of these devices also require an access point from which a signal can be injected and hence are of no use in detecting unmapped or inaccessible cables. Anyone using such a conventional detection device should heed the manufacturer's statement of their limitations. Although such devices as the common metal or mine detector can detect metallic objects, they cannot distinguish between two or more closely spaced pipes, between metal reinforcing bars in concrete and metal pipes, or composition such as concrete or plastic.

The following is a summary of the most commonly used obstacle locating techniques:[94]

1. A visual check of all pipe or cable depths at accessible valve and manhole locations.

2. A survey of all utility maps showing existing installations with the knowledge that many of these maps are inaccurate.

3. After a preliminary survey has been made, a metal detector can be useful in locating misalined pipes or locating previously unsuspected pipes or metallic debris. This device is useful only when used with full knowledge of its limitations as explained in the preceding section.

4. If any doubt exists as to the exact location of any utility lines, especially those of nonmetallic composition, test pits should be dug to verify their suspected location.

There may be other devices employing thermal, geophysical, or other methods for obstacle detection but specific information on such devices is not readily available.

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[92] Electrical World. River-Bed Cables Precisely Located. V. 156, No. 45, Oct. 16, 1961, p. 37.
Young, C. A. Measuring the Depth of Buried Cable. Bell Laboratories RECORD, v. 43, No. 10, November 1965, pp. 399-401.
Zawels, J., and J. Harley. Shielded Underground Cable Detection by Electromagnetic Radiation. Elec. Eng., v. 82, No. 7, July 1963, pp. 472-476.

[93] Page 401 of second work cited in footnote 92.

[94] Trent, Thomas R. Horizontal Boring for Subsurface Utility Installations. Pennsylvania State Univ., Min. Ind. Exp. Sta., Bull. 72, March 1960, p. 67.

TECHNICAL FORECAST

In the following discussion we specifically limit our forecasts to systems whose development trends are known, systems in which we can see the possible adaptation of new or existing technology, and systems about which we have knowledge of a specific research and development program. Any system not specifically mentioned, because of our lack of knowledge or for other reasons, can at least be expected to maintain its present rate of development.

Mechanical Mole

The mole, now pneumatically operated, is being adapted to hydraulic operation which may provide more efficient operation. A guidance and control system for the mole is being developed that will, if successful, allow the operator to guide the mole along a predetermined route from a remote surface position.

Sonic Devices

Sonic devices are expected to play an increasingly important role in driving conduit through the soil because of their high penetration rates. A proposed separation of the power unit and resonator[95] will reduce the size of the machine to permit its placement in a smaller starting pit. The resonator will reportedly be powered by hydraulic lines which will be fed from a pumping unit on the surface (fig. 60).

Diamond Drilling

As an offshoot from Project Mohole, a retractable diamond bit being developed[96] will be ready in about a year or two for field testing. This retractable bit will greatly increase the efficiency of the drilling operation as it will eliminate the need for making and breaking the entire length of drill string in order to change the bit. The bit in its retractable position will be pushed or pumped down the center of the drill string to the bottom of the hole at which time the bit will open for drilling. When the bit is to be replaced, it will be retracted and brought up through the center of the drill string. By eliminating the handling of the drill pipe, this retractable bit will save an estimated 80 percent of total rig time.

Down-the-Hole Drills

Down-the-hole drills have been mentioned briefly in the section on percussive drilling but down-the-hole tools have also been developed for rotary drilling. Down-the-hole tools are a logical development in drilling as they provide power at the bit where it is needed rather than at the surface where

[95] Page 386 of work cited in footnote 39.

[96] Birdwell, H. C. Development of Wireline Retractable Core Bits--A Progress Report. Pres. at 12th Symp. on Exploration Drilling, Oct. 19-21, 1967.

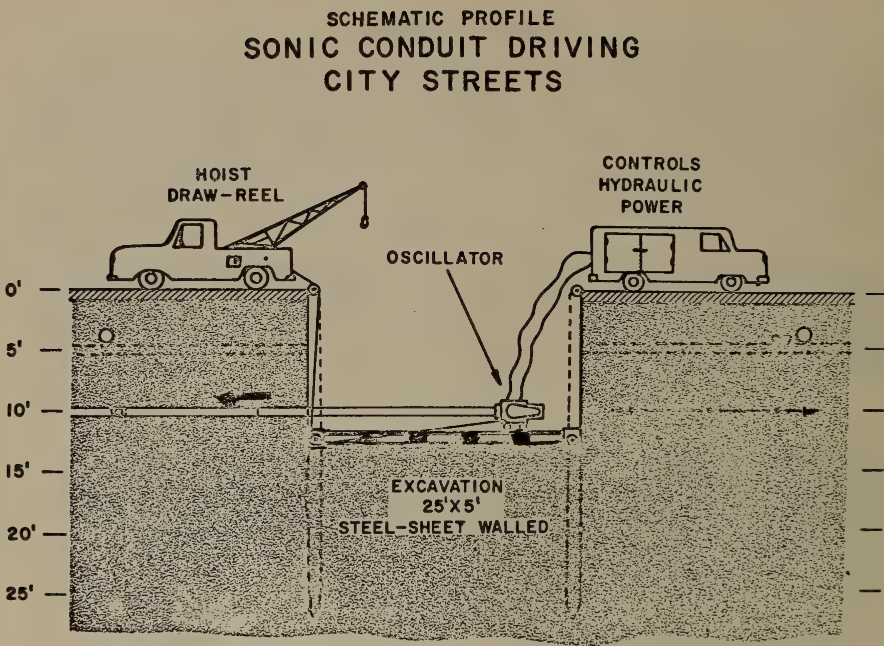

FIGURE 60. - Proposed Sonic Conduit-Driving Device. *(Courtesy, SoniCo Inc.)*

some of it can be dissipated in the long string of drill rods before it reaches the bit. In addition to conserving power, the down-the-hole tool eliminates the problem of drill stem failure since the rods are not subjected to the large forces encountered in boring long holes with surface drills.

Percussive down-the-hole tools have already been used to a limited extent in drilling horizontal holes, but data on these holes are too scanty to permit evaluation at this time. A small down-the-hole percussive drill is shown in figure 61.

Rotary down-the-hole tools such as turbodrills are in effect turbines powered by the drilling fluid pumped through them.[97] Although turbodrills have been used by the oil industry for some years as directional drilling

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[97] Thacher, J. H., and W. R. Postlewaite. Turbodrill Development--Past and Present. World Oil, v. 143, No. 7, December 1956, Drilling Sec., pp. 131-158.

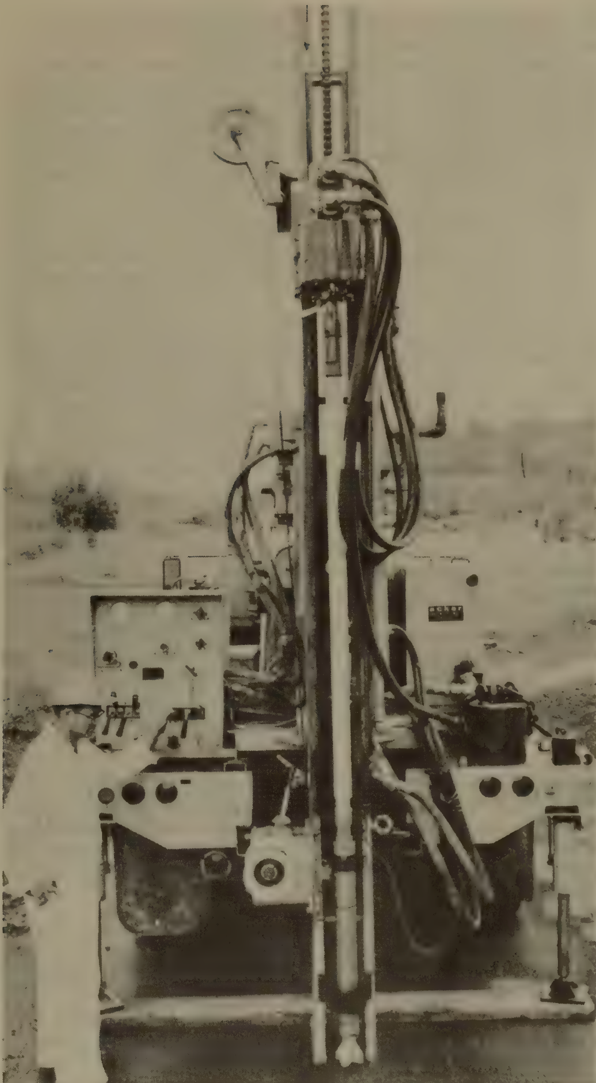

FIGURE 61. - Down-The-Hole Percussive Drill.
(Courtesy, Acker Drill Co., Inc.)

tool;[98] they have not been used in drilling horizontal holes. Some turbodrill manufacturers have expressed interest in this application but to our knowledge no operations have yet been started.

Automatic Wedging

For many years the wedge or whipstock has been the most important tool available for directional drilling in spite of the fact that the wedge requires considerable time and skill to use and the results are not always satisfactory. We now understand that some type of automatic wedging device is being studied but no details are available at this time.

Survey Tools

In preparing this report it became apparent that because of the nature of the drill holes many of the available survey devices are either too slow or too expensive to use.

[98]Leonhardt, Ernst. Mobil Finds Turbodrill Effective in Directional Drilling. World Oil, v. 155, No. 7, December 1962, pp. 63-67.

One possible solution might be the use of a device which could detect the vibrations or noise of the drill bit as it operated under the surface. One such device, the geophone, actually a simplified seismograph, could be used by a man on the surface to locate by triangulation the underground position of the bit. The geophone has in fact been used to plot the position of a vertical diamond drill hole by the noise given off by the bit. Although the test was inconclusive, the noise of the drill bit could be heard distinctly even at a depth of 1,000 ft.[99] At the present time, so far as we know, no research or development work is being done on the geophone as a survey tool.

Support of Hole

At the present time weak drill holes are supported by the pressure of the drilling fluid or by installing steel casing in the hole. For many reasons, neither procedure is entirely satisfactory.

A unique and interesting solution to the problem of hole support may be found in the work of some Russian scientists who studied the effect of direct-current flow through soils.[1] They found that the flow of current through a soil causes a fundamental change in the structure of the soil and strengthens it considerably. The process, called the electrochemical method, in some applications involves the use of a special mixture of clay and binding material and the application of a direct current while in other cases the application of a direct current while in other cases the application of current is all that is required.

Another idea which may prove useful for borehole support involves the continuous forming of cement conduit beneath the surface.[2] The process utilizes a plow and vibratory extruder which are run at depth into the soil much as when planting cable. A concrete mix flows down into the plow and out of a vibratory extruder to form a continuous line of concrete conduit. Originally developed for land drainage, this process may be adaptable to coating the walls of weak boreholes with a concrete shell, or for coating cable as it is planted in the soil for protection against corrosive elements.

SUMMARY

The soil penetration methods are summarized in table 13 and include such important characteristics of each method as drilling capability in soil, maximum borehole-length capability, borehole diameters, system accuracy, penetration rates, and costs. The maximum borehole length[3] and borehole diameter for each method are plotted in figure 62 to allow a quick comparison of the different soil penetration methods.

The rock penetration methods are similarly summarized in table 14; the length and diameter parameters of each system are shown in figure 63.

[99] Leighton, Alan. Application of the Geophone to Mining Operations. BuMines Tech. Paper 277, 1922, pp. 27, 28.

[1] Titkov, N. I., A. S. Korzhuev, V. G. Smolyaninov, V. A. Nikishin, and A. Ya Neretina. Electrochemical Induration of Weak Rocks. Authorized translation from the Russian, Consultants Bureau, New York, 8 pp.

[2] Ede, A. N. Continuously Formed Concrete Tube for Drainage. Agric. Eng., v. 38, No. 12, December 1957, pp. 864-866.

[3] The maximum borehole length given is the longest hole drilled to date but is not necessarily the longest hole that can be drilled with the method.

TABLE 13. - Horizontal soil-penetration methods

Method	Material bored	Maximum hole length, ft	Range of hole diameter, in	Accuracy	Penetration rates, fpm	Cost, dollars per foot of hole
Spoil augering..	Soils, soft rock.	570	2 to 84....	Not specified.....	0.5 to 6....	For 12 in or greater diameter, $1.00 to $4.00 per inch of pipe diameter.
Compacting augering.	Soils........	200	1¼ to 4 (reamed to 8 in).	About 1° error....	2 to 8	$0.10 to $0.20 (direct drilling cost estimate).
Water boring....	Soils, soft rock.	[1]50	2 to 4 (reamed to 18 in).	Not specified.....	Similar to spoil augering.	Similar to spoil augering.
Mechanical mole.	Soils........	100	3-3/4 to 5-7/8.	...do.............	1 to 4....	Not specified.
Pipe pushing....	...do........	200	1 to 108	Error about 1 percent of hole length for large-diameter holes.	0.1 to 0.2 and over.	For 3- to 4-in diameter, $1.90; for 12- to 30-in diameter (lined), $1.50 to $4.00 per inch of hole diameter.
Overburden drilling.	Any material soils and/or rock.	100	4.........	Error about 1 percent of hole length.	0.44 in broken rock and gravel.	Not specified.
Vibratory (sonic).	Soils........	240	Up to 18...	Less than 1 percent error in some cases.	60.........	Do.
Machine tunneling.	...do........	Unlimited	[2]66 to 450.	Excellent......	Up to 0.25 or more.	Costs variable.

[1]Average uninterrupted length.
[2]Present information shows that 50-ft-diam earth tunneling machines are in the design and construction stage.

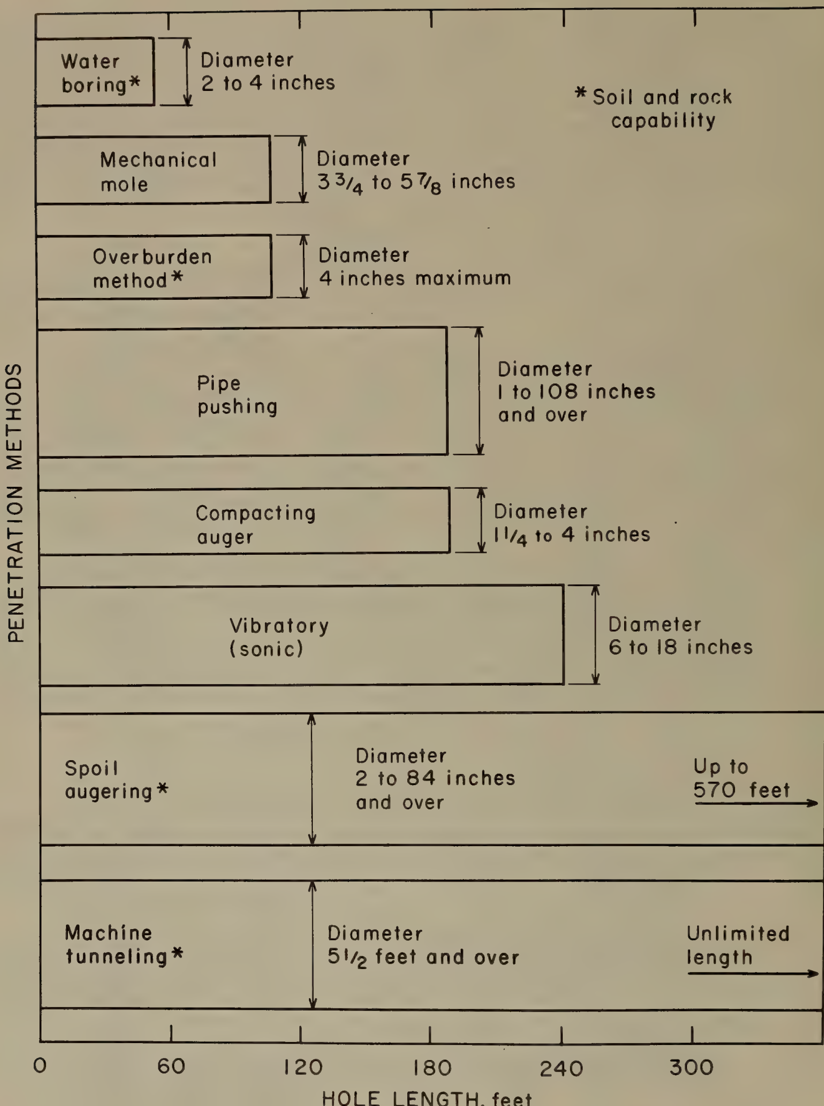

FIGURE 62. - Horizontal Soil Penetration.

TABLE 14. - Horizontal rock-penetration methods

Method	Material bored	Maximum hole length, ft	Range of hole diameter, in	Accuracy	Penetration rates	Cost of hole		Remarks
						Length in feet	Cost per foot	
Diamond drilling.	Any consolidated formation including the hardest rocks, granite, and basalt.	2,000 to 3,000.	Up to 12 (most holes 3 or less).	Deviation 0.5° to 1° or greater.	Very hard rock, 0.1 to 3.0 ipm. Moderately soft, 7.0 to 20.0 ipm.	0- 500 500- 750 750-1,000	\$1.80-\$4.00 4.00- 9.00 7.00-12.00	Conventional method.
Rolling cutter drilling.	Most formations including soft to very hard rock.	500.....	1 to 26 (multibit cutting heads 36 and over.	Unspecified.	Very hard rock, 2 to 8 fph. Soft material, 40 to 1,000 fph.	0- 500 500-1,000 1,000-2,000	\$0.70-\$2.25 1.60- 5.00 2.50- 6.00	Air or water flushing.
Drag-bit drilling.	Soft rocks with no hard streaks, salt, coal, potash, etc.	Not specified.	1 to 3 or more.	Poor, bit tends to wander.	Faster than rolling cutter bits in soft formations.	Unspecified	Unspecified	Water flushing.
Percussive drilling.	Any consolidated formation including the hardest rocks, granite and basalt.	460.....	1 to 5......	Deviation somewhat greater than 0.5±0.3 percent.	Very hard rock, 5 to 30 ipm. Soft rock, 24 ipm or more.	0- 500	\$1.50-\$4.00	Air flushing.
Machine tunneling.	Consolidated formations.	Unlimited	40 to 450...	Excellent	1 fph to 420 fpd.	-	-	Cost not fully ascertained. Depends on diameter and rate of advance.

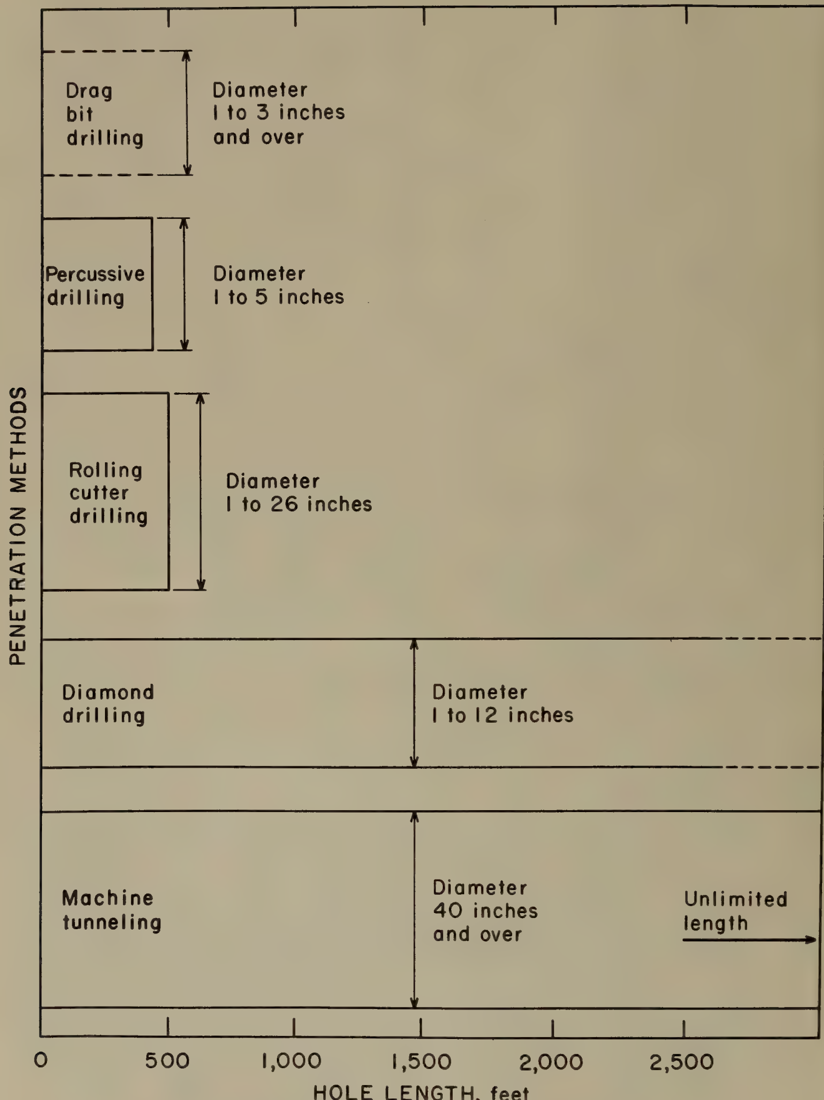

FIGURE 63. - Horizontal Rock Penetration.

EVALUATION

Study of available methods and techniques suitable for boring horizontal holes in soils or rock indicates that the state of the art for burial of power distribution lines which are relatively short (500 ft) and in soil or rock is adequate; the state of the art for burial of power transmission lines which probably involve longer lengths (several thousand ft) in hard or soft material is yet emerging but not adequate to accommodate a national program for power-transmission-line burial. In both, obstacle detection and guidance present operational problems that must be resolved. The cost figures show marked improvement each succeeding year and this trend is expected to continue. Related costs cannot be specified because of the wide variation of such costs among contractors and because emplacement costs are a direct function of the type of material bored. Different localities may thus have different costs despite use of similar equipment.

Throughout the study we have noted a lack of standardization among contractors and manufacturers which is largely due to lack of standardization of its needs by the power industry. Standardization of hole sizes would foster reduction of overall costs for horizontal boring because the manufacturers could focus their developmental attention on specific sizes rather than on a myriad now sought by users.

Another major problem related to the widespread use of inner space for installation of utilities underground is not only that of detecting existing obstacles but also that of mapping boreholes economically, rapidly, and accurately. At the projected rate of underground development for transportation and utilities, inner-space technology will probably encounter problems similar to those of overcrowding in the airspace. An adequate and suitable borehole management system will become necessary and, if effectively planned, can provide a valuable service to national, State, and local political units.

Most of the equipment and techniques used for underground burial of utility lines were developed in response to a concentrated demand. This response by manufacturers and contractors has advanced the state of the art of horizontal boring in soft materials, particularly for power distribution and telephone lines.

A similar concentrated demand for larger diameter holes for power transmission installations in harder materials has not been pressed, a fact that probably accounts for the paucity of developments in this field. As economic incentives are provided, we feel that many of the firms engaged in horizontal drilling or tunneling have the capability to resolve many of the problems associated with making holes for burying transmission lines.

Planners of a program for underground burial of power distribution and transmission lines might consider multipurpose, larger diameter boreholes which could be more accurately driven with tunneling machines. Larger holes could be more economic on a unit basis if other utilities such as water, gas, and sewer could be incorporated in the same hole.

RECOMMENDATION

To advance the state of the art for horizontal boring of holes for power transmission lines installations, we recommend the following:

1. Adequate formulation and definition of the basic problem.

2. A coherent plan for conducting the work.

3. A realistic combination of experimental and developmental approaches in line with the objectives of the program.

4. An adequate analytical framework for the problem to evaluate experimental or developmental results.

5. Sufficient resources to complete the program.

Some of these problems will require engineering research to apply basic scientific knowledge to human affairs; this research could probably best be done by Government or academic groups. Translating these research results into actual equipment and operating techniques could probably best be done by industry.

CONCLUSIONS

1. The state of the art of horizontal boring for buried <u>distribution</u> lines can meet the needs and requirements of the power industry particularly where such burial involves relatively short holes in soil or rock.

2. The state of the art of horizontal boring for buried <u>transmission</u> lines when longer and larger diameter holes are required and when harder rocks are encountered is not adequate. As the demand for the service increases and economic incentives are provided, it is reasonable to assume that equipment and techniques to do the job can be developed.

3. Underground obstacle detection, particularly in highly developed urban areas, remains a critical problem for horizontal boring.

4. Reliable guidance of boring equipment and rapid hole-survey methods need to be developed.

APPENDIX.--MANUFACTURERS OR CONTRACTORS[1].

1. Plows.
2. Trenchers.
3. Spoil augers.
4. Compacting augers.
5. Water borers.
6. Mechanical moles.
7. Pipe pushers.
8. Percussive drills.
9. Vibratory (sonic) conduit drivers.
10. Diamond drills.
11. Rolling-cutter drills.
12. Drag-bit drills.
13. Tunneling machines.
14. Borehole-surveying devices.
15. Directional-control devices.
16. Overburden drills.

[1] The numbers following the names give an indication of the company's capability.

Acker Drill Co., Inc.
P.O. Box 830
Scranton, Pa. 18501
3, 8, 10, 11, 12, 14, 15

Allis-Chalmers
P.O. Box 512
Milwaukee, Wis. 53201
1

American Tractor Equipment Corp.
P.O. Box 1226
Oakland, Calif. 94604
1

Arps Corp.
New Holstein, Wis. 53601
2

Atlas Copco
100 Commerce Way
Hackensack, N. J. 07602
8, 16

Bell Telephone Laboratories, Inc.
Murray Hill, N.J. 97971
1, 2, 3, 4, 5, 6

Bodine Sound-Drive Co.
7877 Woodley Avenue
Van Nuys, Calif. 91406
1, 9

Boring, Inc.
55-14 48th Street
Maspeth, N. Y. 11378
3, 7, 10, 11, 13

Boring & Tunneling Co. of America, Inc.
2902 Rick Road
P.O. Box 14214
Houston, Tex. 77021
3, 7, 13

Boyles Bros. Drilling Co.
10801 North 21st Avenue
Phoenix, Ariz. 85020
10, 11, 12

Boyles Industries Limited
1291 Parker Street
Vancouver 6, British Columbia
10, 11, 12

Calweld
Division of Smith Industries
International, Inc.
P.O. Box 2875
Santa Fe Springs, Calif. 90670
3, 13

Chicago Pneumatic
Oil Tool Division
5000 U.S. Highway 81 South
P.O. Box 1990
Fort Worth, Tex. 76101
4, 8, 10, 11, 12

Christensen Diamond Products Co.
1937 South Second West Street
Salt Lake City, Utah 84110
10, 11, 12, 14, 15

Contender Corp.
433 Community Lane
P.O. Box 297
Woodland, Calif. 95695
1, 4

CRC-Crose International, Inc.
Subsidiary of Crutcher-Rolfs-
Cummings, Inc.
P.O. Box 3227
Houston, Tex. 77001
3, 7

Davis Manufacturing, Inc.
1500 So. McLean Blvd.
Wichita, Kans. 67213
1, 2, 5

Deere & Co.
Moline, Ill. 61265
1, 2

D-Fab Division of the Fruehauf Corp.
Route 202
Montgomeryville, Pa. 18936
2

Drilco Oil Tools, Inc.
3100 Garden City Highway
P.O. Box 3135
Midland, Tex. 79701
10, 11, 12, 15

Dyna-Drill Co.
Division of Smith Industries
International, Inc.
P.O. Box 327
Long Beach, Calif. 90801
10, 11, 15

Eastman Oil Well Survey Co.
P.O. Box 14609
Houston, Tex. 77021
14, 15

E. J. Longyear Co.
76 South 8th Street
Minneapolis, Minn. 55402
3, 10, 11, 12, 14, 15

F. B. Ryan Manufacturing Co., Inc.
Chariton, Iowa 50049
1

Gardner-Denver Co.
Gardner Expressway
Quincy, Ill. 62501
8, 15

Gardner-Denver Co.
1727 E. 39th Avenue
Denver, Colo. 80205
8, 15

Hoffman Brothers Drilling Co.
P.O. Box 426
Punxsutawney, Pa. 15767
10, 11, 12, 14, 15

Hughes Tool Co.
Industrial Products Division
P.O. Box 26306
Dallas, Tex. 75226
13

Hughes Tool Co.
Oil Tool Division
P.O. Box 2539
Houston, Tex. 77001
3, 11, 13, 15

James S. Robbins and Associates, Inc.
500 Wall Street
Seattle, Wash. 98121
13, 15

Kelly Products
Division of Crutcher-Rolfs-
Cummings, Inc.
P.O. Box 3227
Houston, Tex. 77001
1

Lawrence Manufacturing Co.
Subsidiary of Ingersoll Rand Co.
7911 Tenth Avenue South
Seattle, Wash. 98108
13

Melfred Welding & Manufacturing
4236 East Washington Boulevard
Los Angeles, Calif. 90023
5

Midwest Utility Plow & Equipment Corp.
925 N. Bluemound Drive
Appleton, Wis. 54911
1

Mining Equipment Mfg. Corp.
3319 Four Mile Road
Racine, Wis. 53404
7, 13, 15

Mobile Drilling Co., Inc.
3807 Madison Avenue
Indianapolis, Ind. 46204
3, 12

Northern States Power Co.
414 Nicollet Mall
Minneapolis, Minn. 55401
1, 2, 3, 4, 5, 7

Parsons Division of Koehring Co.
200 North 8th Avenue East
Newton, Iowa 50208
1, 2

PCM Division of Koehring Co.
Port Washington, Wis. 53074
3

Pennsylvania Drilling Co.
7201-15 Chartiers Avenue
Pittsburgh, Pa. 15220
3, 10, 11, 12, 14, 15

Reed Drilling Tools
Division of Murphy Industries
P.O. Box 9541
Houston, Tex. 77011
10, 11, 12, 13, 14, 15

Schramm, Inc.
West Chester, Pa. 19380
6

Security Engineering Division
of Dresser Industries
Dallas, Tex. 75221
10, 11, 12, 13

Sodmaster Division of Federal
Industries
3456 North Washington
Minneapolis, Minn. 55412
1, 2

SoniCo, Inc.
10306 Roselle Street
San Diego, Calif. 92121
9

Sperry-Sun Well Surveying Co.
P.O. Box 36363
Houston, Tex. 77036
14, 15

Sprague & Henwood, Inc.
211 W. Olive
Scranton, Pa. 18508
10, 11, 12, 14, 15

The Charles Machine Works, Inc.
P.O. Box 66
West Ditch Witch Road
Perry, Oklahoma 73077
1, 2, 4

The Richmond Manufacturing Co.
P.O. Box 588
Ashland, Ohio 44805
3

The Salem Tool Co.
767 South Ellsworth Avenue
Salem, Ohio 44460
3, 15

The Timken Roller Bearing Co.
Rock Bit Division
Colorado Springs, Colo.
8

Ulrich Manufacturing Co.
Roanoke, Ill. 61561
1

Vermeer Manufacturing Co.
Pella, Iowa 50219
1, 2

Woodland Manufacturing Co.
155 West Main Street
P.O. Box 1235
Woodland, Calif. 95695
1

INT.-BU.OF MINES,PGH.,PA. 12784